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High-K Isomers in Light Superheavy Nuclei by PNC-CSM method

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Abstract. The high-K isomeric states in light superheavy nuclei around A = 250 mass region are investigated by the Cranked Shell Model (CSM) with pairing treated by a Particle-Number Conserving (PNC) method. With including the higher-order deformation ε_6, both of the high$-K$ multi-particle state energies and the rotational bands in ^{254}No and N = 150 isotone are reproduced well. The isomeric state energies and the microscopic mechanism of kinematic moment of inertia variations versus rotational frequency are discussed. The irregularity of the two-neutron $K^\pi = 8^-$ state band at $\hbar\omega \approx 0.17$ in ^{252}No is caused by the configuration mixing with the two-proton $K^\pi = 8^-$ band. .

1 Introduction

In recent decades, intensive studies of the in-beam and decay spectroscopic have been performed on the light well-deformed superheavy nuclei around A = 250 mass region. Increasing experimental spectroscopic data have been reported [1, 2]. Moreover, A = 250 region is one of the typical mass region for presence of the high$-K$ isomers. Numerous isomers (mainly two-particle states) are identified now (see Table 1 in Ref.[3]). Beside the two-particle states, four-particle states are also observed, like the 2.928(3) MeV 184(2)μs isomer in ^{254}No [4] and 247(73)μs isomer in ^{254}Rf [5]. These experimental data provide valuable informations to explore the structure of the light superheavy nuclei and to test the nuclear theoretical models. Moreover, through the investigations of single-particle structure of the light superheavy nuclei, one can predict more precisely the next spherical magic number beyond ^{208}Pb. This is crucial for producing the superheavy elements. In the present work, the high$-K$ multi-particle state bands in ^{254}No and the $K^\pi = 8^-$ isomeric bands observed systematically in N = 150 isotone are investigated by Cranked Shell Model with pairing correlation treated by Particle-Number-Conserving method.

2 Theoretical method

The cranked shell model hamiltonian of an axially symmetric nucleus in the rotating frame is $H_{\rm CSM} = H_0 + H_{\rm P} = \sum_n (h_{\rm Nil} - \omega j_x)_n + H_{\rm P}(0) + H_{\rm P}(2)$, where $h_{\rm Nil}$ is the Nilsson Hamiltonian, $-\omega j_x$ is the Coriolis force with the cranking frequency ω about the x axis (perpendicular to the nuclear symmetry z axis). $H_{\rm P}$ is the pairing including monopole and quadrupole pairing

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Table 1. Multi-particle states predicted by the PNC-CSM calculations.

nuclei	K^π	Configuration	E_x(MeV)	E_x^{exp}(MeV)
^{250}Fm	8^-	$\nu 9/2^-[734] \otimes \nu 7/2^+[624]$	1.213	1.199
^{252}No	8^-	$\nu 9/2^-[734] \otimes \nu 7/2^+[624]$	1.139	1.254
^{254}No	3^+	$\pi 7/2^-[514] \otimes \pi 1/2^-[521]$	1.154	0.988
^{254}No	8^-	$\pi 9/2^+[624] \otimes \pi 7/2^-[514]$	1.272	1.297
^{254}No	10^+	$\nu 9/2^-[734] \otimes \nu 11/2^-[725]$	2.526	2.013
^{254}No	16^+	$\{\nu 9/2^-[734] \otimes \nu 7/2^+[613]$ $\pi 9/2^+[624] \otimes \pi 7/2^-[514]\}$	3.213	2.928

correlations. H_{CSM} is diagonalized directly in a truncated Cranked Many-Particle Configuration (CMPC) (Fock) space. Therefore, particle number is conserved and Pauli blocking effects are taken into account exactly.

The Nilsson parameters (κ, μ) which are optimized to reproduce the experimental level schemes for heavy nuclei around $A = 250$ mass region in Refs. [6, 7] are used. The axially symmetric deformation parameters $\varepsilon_{2,4,6}$ are taken from Refs. [7, 8]. The CMPC space is constructed in the proton $N = 4, 5, 6$ and neutron $N = 6, 7$ shells. The dimensions of the CMPC space are about 1000 and the corresponding effective monopole and quadrupole pairing strengths are $G_0 = 0.25$ MeV and $G_2 = 0.02$ MeV for both of proton and neutron for all the studied nuclei.

3 High−K multi-particle states

Multi-particle state configurations and energies in ^{254}No and in the $N = 150$ isotone calculated by the PNC-CSM are listed in Table 1. A better reproduction of the experimental state energies will be obtained by including of ε_6 deformation. The $K^\pi = 8^-$ isomer state is observed systematically in this mass region. Unlike the $K^\pi = 8^-$ isomer in the $N = 150$ isotones, whose configuration is accepted as two-neutron $\nu 9/2^-[734] \otimes \nu 7/2^+[624]$ state in the literature, the configuration of the observed $K^\pi = 8^-$ isomer state in ^{254}No is in dispute up to now. In the PNC-CSM calculation, the lowest 8^- state in ^{254}No has the two-proton $\pi 9/2^+[624] \otimes \pi 7/2^-[514]$ configuration with energy 1.272 MeV, which reproduces very well the experimental value 1.297(2) MeV.

The experimental kinematic moment of inertia $J^{(1)}$ among the ground state band (GSB) and the $K^\pi = 8^-$ state band in ^{254}No and in $N = 150$ isotone (^{252}No and ^{250}Fm) are compared with the PNC-CSM calculations in Figure 1. The theoretical results reproduce the experimental data well. The authors in Ref. [9] claimed that there is an irregularity of the experimental dynamical moments of inertia $J^{(2)}$ at $\hbar\omega \approx 0.17$ MeV (spin $I \sim 17\hbar$) of the $K^\pi = 8^-$ band in ^{252}No (see Figure 6 in Ref.[9]), and they suggested that this irregularity is due to the band crossing with a $K^\pi = 2^-$ octuple band. The PNC-CSM calculations show that the behaviors of $J^{(1)}$ for two-neutron $K^\pi = 2^-$ (or 7^-), $\nu 9/2^-[734] \otimes \nu 5/2^+[622]$ state at $\hbar\omega \geq 0.15$ MeV is similar with that for $K^\pi = 8^-$ state. But its energy is too high. This might imply that the irregularity in MoI is not from the crossing with the two-neutron $K^\pi = 2^-$ (or 7^-) state. The $J^{(1)}$ for the two-proton $K^\pi = 8^-$, $\pi 9/2^+[624] \otimes \pi 7/2^-[514]$ state shows a slight upbending at $\hbar\omega \approx 0.17$ MeV, and the gradual increase afterwards can reproduce the experimental variations well. Thus, if the assumption that the irregularity of MoI at $\hbar\omega \geq 0.17$ MeV coming from band-crossing is correct, it might result from the crossing with the two-proton $\pi 9/2^+[624] \otimes \pi 7/2^-[514]$ configuration, which itself is mixed with $\pi 9/2^+[624] \otimes \pi 1/2^-[521]$ configuration.

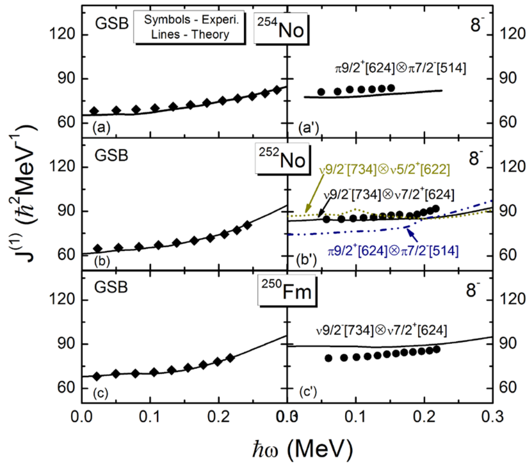

Figure 1. (Color online) Kinematic moment of inertia $J^{(1)}$ versus rotational frequency $\hbar\omega$ of the ground state bands [(a),(b),(c)] and the $K^{\pi} = 8^{-}$ state bands [(a′),(b′),(c′)] in ^{254}No and in $N = 150$ isotone (^{252}No and ^{250}Fm). Theoretical calculations are denoted by lines and experiment data are denoted by solid symbols.

4 Summary

In summary, the Cranked Shell Model with pairing correlations treated by a Particle-Number Conserving method is used to study the multi-particle states observed in ^{254}No and in the $N =$ 150 isotone. Calculations including high-order deformation ε_6 lead to a better reproduction of the experimental data. The irregularity of the two-neutron $K^{\pi} = 8^{-}$ state band in ^{252}No is analysed together with other low-lying two-particle state bands. The abnormal behavior at $\hbar\omega \approx 0.17$ of the MoI is caused by the band cross with two-proton $K^{\pi} = 8^{-}$ band.

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