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

Xiao-Tao He¹,*

¹College of Material Science and Technology, Nanjing University of Aeronautics and Astronautics, Nanjing 210016, China

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 \(\varepsilon_6\), both of the high-\(K\) multi-particle state energies and the rotational bands in \(^{254}\text{No}\) 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 \(^{252}\text{No}\) 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)\(\mu s\) isomer in \(^{254}\text{No}\) [4] and 247(73)\(\mu s\) isomer in \(^{254}\text{Rf}\) [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 \(^{208}\text{Pb}\). This is crucial for producing the superheavy elements. In the present work, the high-\(K\) multi-particle state bands in \(^{254}\text{No}\) 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

\[ H_{\text{CSM}} = H_0 + H_P = \sum_n (h_{\text{Nil}} - \omega j_z)_n + H_P(0) + H_P(2), \]

where \(h_{\text{Nil}}\) is the Nilsson Hamiltonian, \(-\omega j_z\) is the Coriolis force with the cranking frequency \(\omega\) about the \(x\) axis (perpendicular to the nuclear symmetry \(z\) axis). \(H_P\) is the pairing including monopole and quadrupole pairing.

*e-mail: hext@nuaa.edu.cn

© The Authors, published by EDP Sciences. This is an open access article distributed under the terms of the Creative Commons Attribution License 4.0 (http://creativecommons.org/licenses/by/4.0/).
experimental dynamical moments of inertia experimental data well. The authors in Ref. [9] claimed that there is an irregularity of the compared with the PNC-CSM calculations in Figure 1. The theoretical results reproduce the implied that the irregularity in MoI is not from the crossing with the two-neutron is observed systematically in this mass region. Unlike the Kπ up to now. In the PNC-CSM calculation, the lowest 8−ν is isotones, whose configuration is accepted as two-neutron configuration. A better reproduction of the experimental value 15 MeV is similar with that for Kπ configuration, which itself is mixed with π9/2−[734] ⊗ π7/2−[514] configuration.

### 3 High−K multi-particle states

Multi-particle state configurations and energies in 254No and in the N = 150 isotope calculated by the PNC-CSM are listed in Table 1. A better reproduction of the experimental state energies will be obtained by including of ε0 deformation. The Kπ = 8− isomer state is observed systematically in this mass region. Unlike the Kπ = 8− isomer in the N = 150 isotones, whose configuration is accepted as two-neutron ν9/2−[734] ⊗ ν7/2+[624] state in the literature, the configuration of the observed Kπ = 8− isomer state in 254No is in dispute up to now. In the PNC-CSM calculation, the lowest 8− state in 254No has the two-proton π9/2+[624] ⊗ π7/2−[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 Kπ = 8− state band in 254No and in N = 150 isotope (252No and 250Fm) 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 ℏω ≈ 0.17 MeV (spin I ∼ 17h) of the Kπ = 8− band in 252No (see Figure 6 in Ref.[9]), and they suggested that this irregularity is due to the band crossing with a Kπ = 2− octuple band. The PNC-CSM calculations show that the behaviors of J(1) for two-neutron Kπ = 2− (or 7−), ν9/2−[734] ⊗ ν5/2+[622] state at ℏω ≥ 0.15 MeV is similar with that for Kπ = 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 Kπ = 2− (or 7−) state. The J(1) for the two-proton Kπ = 8−, π9/2+[624] ⊗ π7/2−[514] state shows a slight upbending at ℏω ≈ 0.17 MeV, and the gradual increase afterwards can reproduce the experimental variations well. Thus, if the assumption that the irregularity of MoI at ℏω ≥ 0.17 MeV coming from band-crossing is correct, it might result from the crossing with the two-proton π9/2+[624] ⊗ π7/2−[514] configuration, which itself is mixed with π9/2+[624] ⊗ π1/2−[521] configuration.

| nuclei     | Kπ   | Configuration                                        | $E_x$(MeV) | $E^{272}$(MeV) |
|------------|------|-----------------------------------------------------|------------|---------------|
| 250Fm      | 8−   | ν9/2−[734] ⊗ ν7/2+[624]                               | 1.213      | 1.199         |
| 252No      | 8−   | ν9/2−[734] ⊗ ν7/2+[624]                               | 1.139      | 1.254         |
| 254No      | 3+   | π7/2−[514] ⊗ π1/2−[521]                               | 1.154      | 0.988         |
| 254No      | 8−   | π9/2+[624] ⊗ π7/2−[514]                               | 1.272      | 1.297         |
| 254No      | 10+  | ν9/2−[734] ⊗ ν11/2−[725]                              | 2.526      | 2.013         |
| 254No      | 16+  | {ν9/2−[734] ⊗ ν7/2+[613]}                            | 3.213      | 2.928         |
|            |      | π9/2+[624] ⊗ π7/2−[514]                               |            |               |
experimental dynamical moments of inertia compared with the PNC-CSM calculations in Figure 1. The theoretical results reproduce the irregularity in MoI is not from the crossing with the two-neutron isotones, whose configuration is accepted as two-neutron multi-particle states in 254No and in the literature, the configuration of the observed state energies will be obtained by including of G symmetric deformation parameters

\[ \epsilon(254No) = 1000 \text{ and the corresponding } \epsilon(250Fm) \]

Hence, the behaviors of \( \kappa, \mu \) effects are taken into account exactly. The experimental kinematic moment of inertia \( J^\omega \) is similar with that for \( \pi^+ \) band in 252No (see Figure 6 in Ref.[9]), and they suggested that this irregularity is coming from band-crossing is correct, it might result from the crossing with the two-proton state bands [(a),(b),(c)] and the \( \kappa^\prime = 8^- \) state bands [(a'),(b'),(c')] in 254No and in \( N = 150 \) isotope (252No and 250Fm). 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 254No and in the \( N = 150 \) isotope. Calculations including high-order deformation \( \epsilon_6 \) lead to a better reproduction of the experimental data. The irregularity of the two-neutron \( \kappa^\prime = 8^- \) state band in 252No 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 \( \kappa^\prime = 8^- \) band.

### Acknowledgments

This work was supported by the National Natural Science Foundation of China under Grant No. 11775112 and 11275098.

### References

[1] R.D. Herzberg, P.T. Greenlees, Prog. Part. Nucl. Phys. 61, 674 (2008)
[2] R.D. Herzberg, J. Phys. G: Nucl. Part. Phys. 30, R123 (2004)
[3] F. Kondev, G. Dracoulis, T. Kibédi, At. Data Nucl. Data Tables 103–104, 50 (2015)
[4] R. Clark, K. Gregorich, J. Berryman, M. Ali, J. Allmond, C. Beausang, M. Cromaz, M. Deleplanque, I. Dragojević, J. Dvorak et al., Phys. Lett. B 690, 19 (2010)
[5] H.M. David, J. Chen, D. Seweryniak, F.G. Kondev, J.M. Gates, K.E. Gregorich, I. Ahmad, M. Albers, M. Alcorta, B.B. Back et al., Phys. Rev. Lett. 115, 1 (2015)
[6] Z.H. Zhang, J.Y. Zeng, E.G. Zhao, S.G. Zhou, Phys. Rev. C 83, 1 (2011)
[7] Z.H. Zhang, X.T. He, J.Y. Zeng, E.G. Zhao, S.G. Zhou, Phys. Rev. C 85, 1 (2012)
[8] P. Möller, J. Nix, At. Data and Nucl. Data Tables 59, 185 (1995)
[9] B. Sulignano, C. Theisen, J.P. Delaroche, M. Girod, J. Ljungvall, D. Ackermann, S. Antalic, O. Dorvaux, A. Drouart, B. Gall et al., Phys. Rev. C 86, 1 (2012)