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Systematical study of high-spin rotational bands in neutron-deficient Kr isotopes by the extended projected shell model

Xin-Yi Wu [a,b], S.K. Ghorui [a,b,c], Long-Jun Wang [a,b], K. Kaneko [d], Yang Sun [a,b,c]

[a] *Department of Physics and Astronomy, Shanghai Jiao Tong University, Shanghai 200240, People's Republic of China*
[b] *Collaborative Innovation Center of IFSA (CICIFSA), Shanghai Jiao Tong University, Shanghai 200240, People's Republic of China*
[c] *State Key Laboratory of Theoretical Physics, Institute of Theoretical Physics, Chinese Academy of Sciences, Beijing 100190, People's Republic of China*
[d] *Department of Physics, Kyushu Sangyo University, Fukuoka 813-8503, Japan*

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Abstract

We analyze the high-spin structure of the even–even $^{72–80}$Kr isotopes using the Projected Shell Model (PSM). With the help of the Pfaffian formulas, we have vigorously extended the quasi-particle (qp) basis of the PSM code and applied in this mass region for the first time. We consider a sufficiently large multi-qp configuration space in order to describe high-spin rotational behavior. The results show that the calculation can reproduce most of the known rotational bands with positive- or negative-parity. Moreover, some side bands appearing in the near-yrast region are predicted. The main structure for each band is discussed in terms of multi-qp configurations. The variations in moment of inertia with spin are explained in terms of successive band crossings among the 2-qp, 4-qp, 6-qp, and 8-qp states. The $B(E2)$ transition probabilities in these bands are also calculated. To further understand the high-spin behavior of these neutron-deficient nuclei and to confirm predictions of the present work, good high-spin data, especially for $B(E2)$ transitions, are called for.

E-mail address: sunyang@sjtu.edu.cn (Y. Sun).

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Keywords: Projected shell model; High spin structure; Multi-quasiparticle configurations; Pfaffian formulas

1. Introduction

The neutron-deficient Kr nuclei in the mass range $A = 72$–80 lie in the transitional region [1] and have very different half-lives [2], ranking from seconds for the self-conjugate nucleus ^{72}Kr, minutes for ^{74}Kr, hours for ^{76}Kr, and stable for ^{78,80}Kr. These Kr isotopes exhibit different structures, and therefore, are often used as examples to probe underlying physics of various nuclear phenomena. As for instance, the $N = Z = 36$ isotope ^{72}Kr is a well-known example for appearance of the oblate-prolate shape-coexistence in the low-energy region [3–5]. It also shows the most marked effect of 'delayed alignment' at high spins, and this phenomenon was suggested [6] to be an important tool to probe the neutron–proton pairing correlations in nuclei. Recently it has been discussed that the shape coexistence and shape transition in this self-conjugate isotope can be used to probe the tensor force in the nuclear many-body Hamiltonian [7]. ^{74}Kr, on the other hand, is a known example that represents the first observed case of nontermination of rotational bands at $I = I_{max}$, from which a new question emerged about the understanding of the rotational behavior at the extremes of angular momentum [8]. Shape-coexistence near the ground state was also observed in ^{74,76}Kr [9]. The isotope ^{78}Kr is among the few known nuclei in the nuclear chart where two-neutrino and neutrinoless double-β decays can be studied [10].

Owing to the fruitful structures, the Kr isotopic chain is an ideal testing ground for theoretical models. During the past years, many high-quality high-spin data for these Kr isotopes have been accumulated. For example, the high-spin structure of ^{74}Kr was studied using fusion-evaporation reaction by Valiente-Dobón et. al. [8], and the positive-parity yrast band up to spin $32\hbar$ and two negative-parity bands up to spin $35\hbar$ were obtained. These high-spin states probe the properties of nuclei under the extremes of angular momentum as well as the shape changes during the fast-rotation. Hence these nuclei are suitable examples to study the interplay between collective motion and single-particle excitations, which is one of the most important subjects in nuclear structure physics [11,12]. However, most of the prior theoretical works on Kr nuclei are mainly concentrated on the discussion of shape changes at the low-spin region [13–18], except one earlier work by using the complex version of the Excited VAMPIR [19], which discussed somewhat higher spin states, up to $I = 20\hbar$ in ^{72}Kr and $28\hbar$ in ^{74}Kr. Thus, a systematical study for the high-spin states of these Kr isotopes is currently lacking.

The Projected Shell Model (PSM) [20] was initially developed to describe high-spin structures of deformed nuclei [21]. The model space includes angular-momentum-projected multi-quasiparticle (qp) configurations, suitable for the discussion of deformed nuclei under fast rotation. The early version of the PSM was confined in a small qp-configuration space, which included up to 4-qp configurations for even–even nuclei, 3-qp configurations for odd-mass nuclei, and 2-qp configurations for odd–odd nuclei [20,22]. The reason for the basis restriction is partially because, since the essential computation efforts of the PSM are to calculate the rotated matrix elements of multi-qp states using the generalized Wick's theorem [20], it would encounter a combinatorial complexity associated with practical applications when more than 4-qp states are included [23]. To describe the current high-spin data, we have vigorously extended the quasiparticle (qp) basis recently to include qp states beyond 4-qp, and made an initial application for the very high-spin states in some heavy, deformed nuclei [24,25]. The successful description of rare-earth nuclei [24,25] with the enlarged qp configuration space motives us to further test the extended PSM model for medium mass nuclei around $A \sim 80$ region in a systematical manner.

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