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Description of all observed rotational bands in ^{128}Pr

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Abstract The configuration-dependent cranked Nilsson-Strutinsky approach was used to investigate the rotational structures in ^{128}Pr and signature splittings of some observed bands could be well described quantitatively at high spin. Its modified model was used to calculate special configurations in order to distinguish the N=4 $d_{3/2}s_{1/2}$ and $g_{7/2}d_{5/2}$ orbitals. All observed bands were compared with the calculated configuration assigned to the band and the agreement between experiment and theory is remarkable.

Key words rotational band, configuration, deformation, signature splitting

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1 Introduction

The $A = 130$ mass region is an important laboratory to understand the role of different, e.g. intruder and extruder, orbitals in the valence space on nuclear deformation and signature splitting at high spin. Mechanisms for the origin of enhanced deformation in this region are investigated by the bands built on these orbitals. The recent experimental results of odd-odd ^{128}Pr nucleus[1, 2] were reported and there are 6 signature partner bands and one decoupling band were observed up to spin 39^+, $36^-\hbar$. In this paper we use the configuration-dependent cranked Nilsson-Strutinsky (CNS) approach[3, 4] to investigate all of the observed bands of ^{128}Pr. The observed band 1 of ^{128}Pr and the calculated configuration assigned to the band have been studied in Ref.[5]. It is important that the CNS calculations of fixed configurations should well or reasonably reproduce all of the observed bands of ^{128}Pr at high spin. The notation to label the configurations (relatively to the ^{100}Sn core) used later is $[\mathrm{p_1p_2, n_1(n_2)}] \equiv \pi(g_{9/2})^{-\mathrm{p_1}} (h_{11/2})^{\mathrm{p_2}} \otimes \nu(h_{11/2})^{\mathrm{n_1}}\ (h_{9/2}f_{7/2})^{\mathrm{n_2}}$, where minus symbol means holes and $\mathrm{n_2}$ will be omitted if no particle in the $h_{9/2}f_{7/2}$ orbitals.

2 Discussion

Based on the CNS calculations for ^{128}Pr, and comparing theoretical results with experimental data in the tendency of energy with increasing spin, the orbitals near the Fermi surface, relative energy among bands, band crossing and signature splitting, the configurations of experimental bands were assigned as that shown in Table 1. In Table 1, +- means signature of the orbital occupied by the last single nucleon; u, g, and s for distinguishing configurations means unfavored, only one neutron occupied the $1g_{7/2}$, [402 5/2], and $3s_{1/2}$, [411 1/2], orbitals, respectively; $g_{7/2}/s_{1/2}$ means neutron number in the occupied [402 5/2]/[411 1/2] orbitals; (ε_2,γ) is obtained at spin I=30 or 31$\hbar$ where pairing is negligible. To illustrate, the detailed structure of the [03,7] terminating states for bands 1 and 3 is $\pi\left[(h_{11/2})^{3-,+}_{13.5}(g_{7/2}d_{5/2})^{6}_{12,11}\right]_{25.5,24.5}\otimes \nu\left[(h_{11/2})^{7\pm}_{17.5}(g_{7/2}d_{5/2})^{10}_{10}(d_{3/2}s_{1/2})^{2}_{2}\right]_{29.5}$ =55,54, where the subscripts are the possible spin contributions from the occupied valence orbitals forming the configurations at the oblate ($\gamma = 60°$) axis. These observed and calculated bands are shown in Fig.1 and the calculated shape trajectories as a function of spin for selected bands are shown in Fig.2. From Fig.1 one

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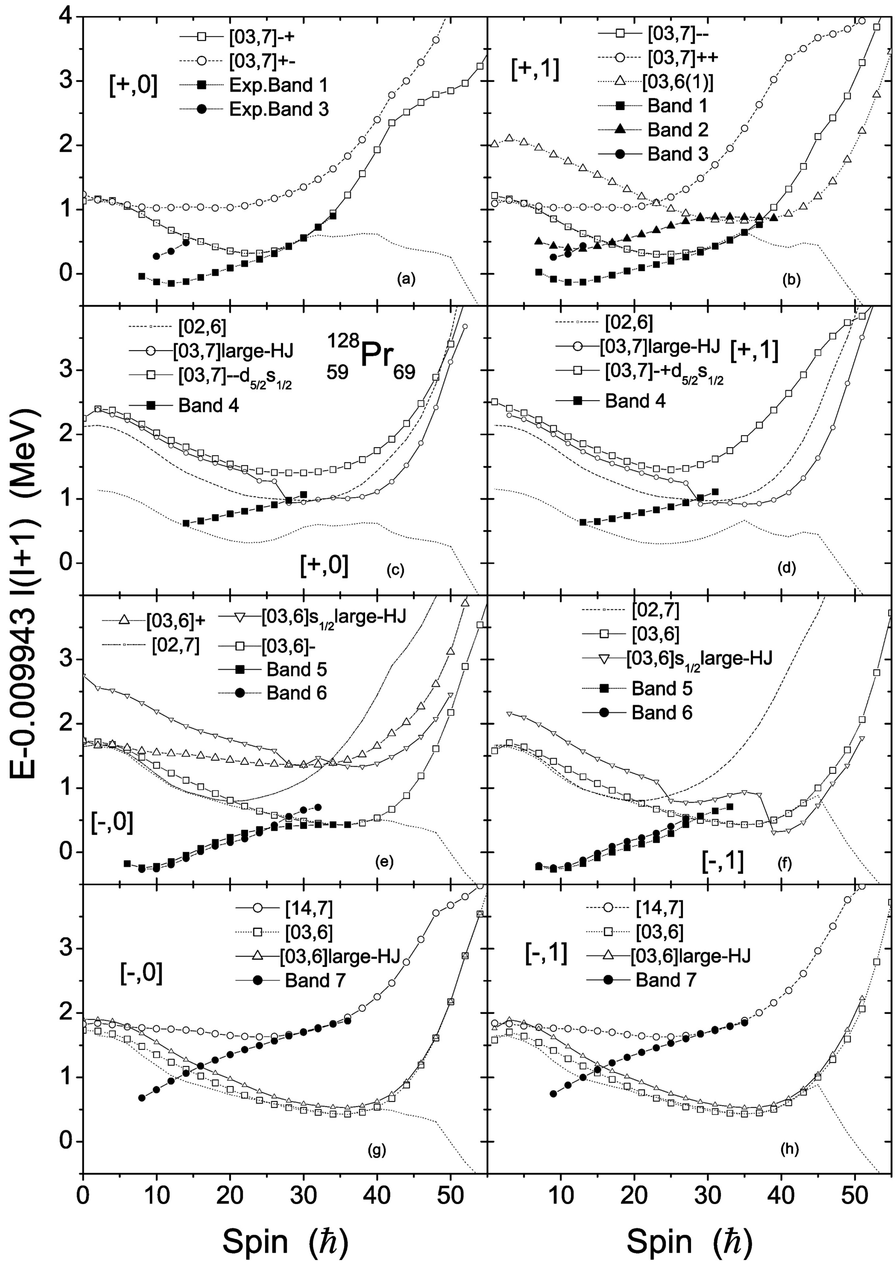

Fig. 1. Total energy versus spin for all observed and specially calculated bands in ^{128}Pr. The energies are given relative to a rigid rotation reference $(\hbar^2/2J_{\rm rig})I(I+1)$. The calculated yrast lines are indicated by dotted lines. The open symbols indicate the theoretical data and solid symbols the experimental data. $+-$ means signature of the N=5 orbital occupied by the last single nucleon. Large-HJ means the CNS calculations are performed with the modified CNS model.

Table 1. Configurations assigned to all experimental bands in ^{128}Pr.

Exp.band	proton		neutron			deformation
	$g_{9/2}$	$h_{11/2}$	$h_{11/2}$	$h_{9/2}$	$g_{7/2}/s_{1/2}$	(ε_2,γ)
1 [03,7]	0	3-	7±	0	0/2	(0.26,0)
2 [03,6(1)]	0	3-	6	1+	0/2	(0.28,2)
3 [03,7]u	0	3+	7±	0	0/2	(0.26,0)
4 [03,7]gs	0	3-	7±	0	1/1	(0.25,-5)
5 [03,6]s	0	3-	6	0	2/1	(0.27,-14)
6 [03,6]g	0	3-	6	0	1/2	(0.25,0)
7 [14,7]	-1±	4	7-	0	0/2	(0.29,-2)

can see that the calculated bands are in very good or reasonable agreement with the experimental bands at high spin. The large differences at low spin are due to the CNS model used here without pairing which is important at low spin. For comparison the observed all positive parity bands, bands 5 and 6, and band 7 have been renormalized 0.58, 0.50, and 0.81 MeV at spin 35, 36, and 34$\hbar$, respectively. The signature splittings of configuration [03,7] in the $I \geqslant 20\hbar$ region[5] and [14,7] in the observed spin region were in very good agreement with that of corresponding experimental bands 1 and 7, respectively. The comparison between normal two-group, e.g. high-j group $g_{9/2}$ and low-j group $g_{7/2}d_{5/2}d_{3/2}s_{1/2}$ for N=4, and modified large high-j two-group, e.g. $g_{9/2}g_{7/2}d_{5/2}$ and $d_{3/2}s_{1/2}$, CNS calculations for [03,6] is shown in Fig.1 (g) and (h).

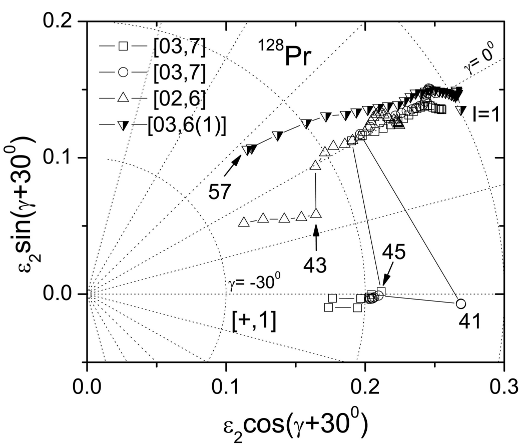

Fig. 2. Calculated shape trajectories as a function of spin in the (ε_2, γ) plane for specific configurations of ^{128}Pr. The step in spin is $2\hbar$.

The difference of observed bands 5 and 6, assigned configurations [03,6] with last single neutron occupied the $3s_{1/2}$ [411 1/2] and $1g_{7/2}$ [402 5/2] orbitals , respectively, is quite small and there is no such similar orbitals near the neutron Fermi surface so the description for band 5 is not good enough even if by the modified large high-j two-group CNS calculations to distinguish these $d_{3/2}s_{1/2}$ and $g_{7/2}d_{5/2}$ orbitals, see Fig.1(e) and (f). Note that such a distinction is only possible at pretty small deformations and not always even in that case due to the orbital mixing, see Fig.1(f). The observed bands 5 and 6 with $\alpha = 0$ has a band crossing at $I = 26$ so their configurations are exchanged too, see Fig.1(e).

For the signature inversion in the low spin region it could not be reproduced by the calculated [03,7] configuration because of the CNS model without pairing or without changing the negative γ rotating axis into the positive γ rotating axis as in Ref.[6]. We could reproduce it by fixed deformation calculations, e.g. at $(\varepsilon_2, \gamma, \varepsilon_4) = (0.29, 20^0, 0.025)$ with configuration [03,7]. ε_4 was found to play an important role in reproducing the signature splitting of observed bands in ^{128}Pr, about 0.025 for [03,7]. No favorable band terminating state was found in ^{128}Pr in the CNS calculations because the so-called negative γ driving force is strongly in action, see Fig. 2.

3 Conclusion

The CNS approach was used to study the rotational structures at high spin in ^{128}Pr. The modified CNS approach was used to calculate special configurations in order to distinguish the N=4 $3s_{1/2}$ and $1g_{7/2}$ [402 5/2] orbitals. All observed bands were compared with the calculated configuration assigned to the band and very good or reasonable agreement between experiment and theory was obtained. Signature splittings of some observed bands could be well described quantitatively at high spin. ^{128}Pr is a quite good axial symmetry nucleus with quadrupole deformation ε_2 about 0.29 and small decreasing with increasing spin. ε_4 plays an important role in the signature splitting calculations and must be included.

The difference between the observed bands 5, 6 and the calculated [03,6] configuration assigned to the band may be caused by the orbital mixing which is very difficult to distinguish at large deformation and rapid rotation. The really situation for many body quantum system is much more complicated than that was assumed by the CNS model. It could be the configurations [03,6] with different N=4 orbitals and [02,7] mixing together to form the observed bands 5 and 6.

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