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Rotational Band Structure in Doubly Odd ^{170}Ta

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High-spin states in ^{170}Ta have been studied via ^{159}Tb (^{16}O, 5nγ) ^{170}Ta reaction at 105 MeV beam energy. Three rotational bands were observed among which one nondistorted band and an unfavored $\Delta I = 2$ $E2$ sequence in a semidecoupled are newly found by this work. The possible quasiparticle configurations of these bands are also discussed in this paper.

Key words: rotational band in doubly odd nucleus, coupling schemes, signature splitting, semidecoupled band.

The study of band structure in the deformed doubly odd nuclei has recently become an interesting topic. For the heavier nuclei in the rare-earth region, the well-investigated yrast bands are normally based on the $\pi[h_{11/2}] + \nu[i_{13/2}]$ quasiparticle configuration and systematically show a phenomenon of the so-called signature inversion at low rotational frequencies before first backbend [1], while for the nuclei at the upper part of this region, a variety of band structures may occur corresponding to the different coupling schemes between the odd proton and the odd neutron [2,3]. These rotational bands near the yrast line should be populated with comparable population ratio by using (HI, xn) reactions and could be observed by using the standard technique of the in-beam γ-ray spectroscopy. When Bacelar, *et al.* studied the high-spin states in ^{171,173}Ta, they observed three rotational bands and attributed them to ^{170}Ta [4], and thought that the most strongly populated band might be based on the $\pi[h_{11/2}] + \nu[i_{13/2}]$ quasiparticle configuration and the other two bands might be the signature partners of $\pi 1/2^-[541] + \nu[i_{13/2}, \alpha = \pm 1/2]$ configuration. These results have been collected in the most recent

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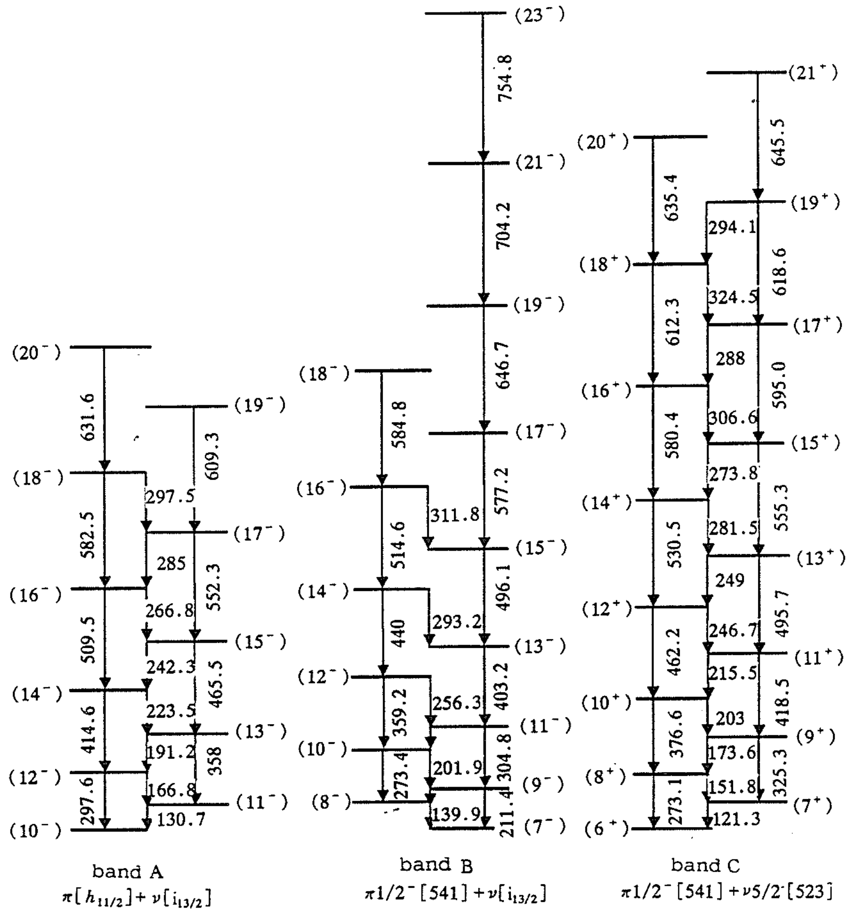

Fig. 1
Proposed level scheme for ^{170}Ta by this work.

compilation [5]. However, our careful analysis indicates that the band 3 in Ref. [4] should be the gsb in ^{170}Hf. If this consideration is correct, two $\Delta I = 2$ sequences connected by $M1/E2$ transitions should also be observed experimentally as in the case of ^{172}Ta [6]. Furthermore, the $\nu5/2^-[523]$ gsb in ^{169}Hf [7] and the $\pi1/2^-$ [541] decoupled band in ^{169}Ta [8] were both strongly populated in (HI, xn) reactions, it is thus expected that the coupling of a $\pi1/2^-[541]$ proton and a $\nu5/2^-[523]$ neutron should form a rotational band and can be observed in ^{170}Ta.

The experiment has been performed at the In-Beam γ-ray Spectroscopy Terminal in the Institute of Modern Physics, Lanzhou, P.R. China by using ^{159}Tb (^{16}O, 5nγ) ^{170}Ta reaction and 4 BGO (AC) HPGe detectors for γ-ray detections. The ^{16}O (105 MeV) beam was delivered by the sector focusing cyclotron (SFC) of the institute and impinged on the ^{159}Tb (2 mg/cm^2 + 3 mg/cm^2 Pb backings) target. A total of 80 $\times$ 10^6 γ-γ coincidence events were accumulated. The detectors were calibrated by the standard ^{152}Eu and ^{133}Ba sources and also checked by the known in-beam γ-rays from ^{169}Ta and ^{170}Hf. The typical energy resolutions (FWHM) were about 2.0-2.4 keV for the 1332.5 keV γ-ray from the ^{60}Co source. From detailed analysis of the gated spectra, the level scheme of ^{170}Ta consisting of three rotational bands has been constructed as shown in Fig. 1, where the γ-rays energies are given in keV and within an uncertainty of 0.3 keV.

Table 1
First band-crossing frequencies of the related bands for the nuclei near ^{170}Ta.

Nucleus	Band	$\hbar\omega_c$ (MeV)
^{168}Hf	yrast	0.265 (5)
^{170}Hf	yrast	0.265 (5)
^{169}Hf	$\nu\frac{5}{2}^{+}[642]$	0.315 (5)
^{169}Hf	$\nu\frac{5}{2}^{-}[523]$	0.240 (5)
^{169}Ta	$\pi\frac{1}{2}^{-}[541]$	0.305
^{169}Ta	$\pi\frac{9}{2}^{-}[514]$	0.24
^{169}Ta	$\pi\frac{5}{2}^{+}[402]$	0.24
^{170}Ta	$\pi\frac{9}{2}^{-}[514]+\nu[i_{\frac{13}{2}}]$	>0.29
^{170}Ta	$\pi\frac{1}{2}^{-}[541]+\nu[i_{\frac{13}{2}}]$	>0.34
^{170}Ta	$\pi\frac{1}{2}^{-}[541]+\nu\frac{5}{2}^{-}[523]$	0.285 (5)

The band A is consistent with Bacelar's results but several uppermost γ-transitions (323, 324, 646.5, 655.5 keV) have not been identified by the present work. The spin values of the energy levels are suggested according to the systematics of the similar bands in ^{166,168}Ta [9] and ^{170}Ta. This band is most probably based on the $\pi[h_{11/2}]$ + $\nu[i_{13/2}]$ configuration because it shows a well-known behavior of signature inversion which often appeared in other doubly odd nuclei in the rear-earth region.

The band B consists of two $\Delta I = 2$ $E2$ cascades connected by 7 $\Delta I = 1$ $M1/E2$ transitions. This band has an apparent level staggering, indicating the participation of a $\nu[i_{13/2}]$ neutron. On the other hand, the first band crossing frequency is found to be even larger than 0.34 MeV (see Table 1) from the analysis of alignment. Thus it seems very probable that the band B is based one the $\pi 1/2^-[541]$ + $\nu[i_{13/2}]$ configuration and falls into the category of the semidecoupled band [2]. The spins of the levels are determined by a comparison among the semidecoupled bands in ^{170}Ta, ^{172}Ta [6], and the related $\nu[i_{13/2}]$ bands in ^{169,171}Hf [7,10]. In the level scheme proposed by Bacelar, *et al.* [4], a γ cascade of 221 keV-321 keV-400 keV... was assigned to ^{170}Ta as the favored band. This assignment is apparently incorrect due to the discovery of both the favored and the unfavored bands in our work. In fact, the $E2$ γ-transition energies of band 3 in Ref. [4] have almost the same values as those of the gsb in ^{170}Hf, and thus a crossing frequency of about 0.265 (5) MeV can be extracted [3,6]. This crossing frequency is much smaller than expected for the semidecoupled band in this mass region [3]. Therefore the band 3 in Ref. [4] is probably the gsb in ^{170}Hf but not in ^{170}Ta. Of course, the possibility that this band is an identical band in a certain nucleus cannot be completely excluded.

The band C is a newly observed rotational band and based probably on the $\pi 1/2^-[541]$ + $\nu 5/2^-[523]$ quasiparticle configuration. This configuration assignment is concluded mainly by the consideration of both the crossing frequencies [3] for different coupling schemes and the amplitude of signature splitting. The spins of the levels are suggested according to the arguments of the additivity rule for alignments and the similar level spacings with the $\nu5/2^-[523]$ gsb in ^{169}Hf. Furthermore, an analysis of alignment (i_x) shows that with the spins proposed in the level scheme the additivity rule for band C is satisfied. In $\hbar\omega$ = 0.1-0.22 MeV, i_x (Band C) $\approx 3\hbar$, which is very close to i_x (^{169}Ta $\pi1/2^-[541]$ + i_x (^{169}Hf ν $5/2^-[523]$ $\approx 0.8\hbar + 2.0\hbar = 2.8\hbar$. Table 1 shows the extracted crossing frequencies for the related bands in ^{170}Ta and its neighboring nuclei, from which one can see that the two intrinsic states of the $\pi5/2^+[402] + \nu[i_{13/2}]$ and the $\pi1/2^-[541] + \nu5/2^-[523]$ are the most probable candidates. However, an analysis of signature splitting shows that the amplitude of signature splitting for band C is comparable with that for the $\nu5/2^-[523]$ gsb in ^{169}Hf, but much bigger than that for the $\pi5/2^+[402]$ band in ^{169}Ta. Therefore, the signature splitting in band C is most probably due to the participation of a $\nu5/2^-[523]$ neutron and thus the possible configuration of $\pi5/2^+[402]+\nu[i_{13/2}]$ can be ruled out. Kreiner, *et al.* have pointed out that when classifying the rotational bands for doubly odd nuclei, there should be a $\Delta I = 1\hbar$ nondistorted band in doubly odd nucleus when there is a decoupled band in its neighboring odd Z nucleus and a normal band with pure K value in odd N nucleus. The first observation of this new coupling scheme in this work is certainly important for the investigation of the rotational band structure and the corresponding coupling schemes.

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