Eur. Phys. J. A **7**, 19–22 (2000)

THE EUROPEAN PHYSICAL JOURNAL A

EDP Sciences

Short note

Search for decoupled bands in Odd-Odd ^{174}Re

Y.H. Zhang, S.Q. Zhang, W.X. Huang, X.H. Zhou, X.C. Feng, X. Xu, X.G. Lei, Y.X. Guo, S.F. Zhu, J.J. He, Z. Liu, S.J. Wang, Y.X. Luo

Institute of Modern Physics, Chinese Academy of Sciences, Lanzhou 730000, P.R. China

Received: 23 November 1999 / Revised version: 5 January 2000
Communicated by D. Schwalm

Abstract. An effort has been made to search for the decoupled bands in odd-odd ^{174}Re via the ^{159}Tb(^{20}Ne,5nγ)^{174}Re reaction through excitation functions, K x-γ and γ-γ coincidence measurements. The doubly decoupled band and the semidecoupled one have been found in this work. Their quasiparticle configurations are proposed to be $\pi 1/2^-[541] \otimes \nu 1/2^-[521]$ and $\pi 1/2^-[541] \otimes \nu i_{13/2}$, respectively, according to the characteristics of band structures in this mass region. Another band with strongly coupled character is also reported.

PACS. 21.10.Re Collective levels – 23.20.Lv Gamma transitions and level energies – 27.70.+q $150 \leq A \leq 189$

The concept of doubly decoupled band with $\pi 1/2^-[541] \otimes \nu 1/2^-[521]$ configuration has been well established in the deformed odd-odd nuclei of rear-earth mass region [1]. In such a band, both the valence proton and the valence neutron occupy predominantly the $\Omega = 1/2$ orbitals. The unfavored levels (even spin) are highly shifted in energy due to decoupling effect. Consequently, only the favored $\Delta I = 2$ $E2$ cascade similar to the yrast band of neighboring even-even nuclei could be easily observed experimentally such as in several odd-odd Ta, Re, and Ir isotopes [1]. Prior to this work, a search for the doubly decoupled band in ^{174}Re was made; five rotational bands including the doubly decoupled one were proposed and assigned to ^{174}Re [2]. However, the assignment of these rotational bands to ^{174}Re was not confirmed by the excitation function measurement. After the report in [2], a level scheme of ^{175}Re was established consistently by two groups [3,4]. It is surprising that the doubly decoupled band reported in [2] is almost same as the $\pi 1/2^-[541]$ decoupled band in ^{175}Re. Furthermore, other γ transition sequences assigned to ^{174}Re [2] can also be found in the coupled bands of ^{175}Re [3,4]. Thus it seems necessary to reinvestigate the band structures, in particular, to search for the doubly decoupled band in ^{174}Re.

The experiment of standard in-beam γ spectroscopy was performed in the Institute of Modern Physics (IMP), Chinese Academy of Sciences(CAS), using the ^{159}Tb(^{20}Ne,5nγ)^{174}Re reaction. The ^{20}Ne beam was provided by the Self Focussing Cyclotron of the institute. The target is a natural ^{159}Tb metallic foil of 2 mg/cm^2 thickness with a 5 mg/cm^2 Pb backing. A γ-ray detector array including 6 HPGe's with BGO anti-Compton (AC) shields was used. These detectors were divided into two groups positioned at 30^0 and 90^0 with respect to the beam direction. The typical energy resolution of the HPGe detectors was about 2.0∼2.4 keV at Full Width at Half Maximum (FWHM) for the 1332.5-keV line. In order to identify the in-beam γ rays emanating from ^{175}Re (4n channel) or from ^{174}Re (5n channel), the beam energies of 106 MeV and 112 MeV were used during experiment. Two spectra are shown in Fig. 1 where the γ rays from ^{175}Re [3,4] are dominated at 106 MeV (Fig. 1(a)). When the beam energy is increased to 112 MeV, some new γ rays (115, 155, 178, 303, and 408 keV) become stronger. We also measured the decay γ rays to check if ^{174}Re was produced at E_{lab}=112 MeV. It was found that the 243-keV line corresponding to the $4^+ \rightarrow 2^+$ transition in ^{174}W was very strong and has an half-life of 2.36(10) minutes consistent with the $T_{1/2}$=2.42(7) minutes of ^{174}Re evaluated in [5]. This result indicates that ^{174}Re was produced and therefore the coincidence measurement for ^{174}Re was performed at 112-MeV beam energy. A total of 40 millions coincidence events was accumulated. The data were sorted into a 4k×4k matrix after gain matching for further analysis. When the new γ rays (115, 155, 178, 303, and 408 keV) are used as "gates", some cascade γ rays are identified as shown in Fig. 2. The main contaminant in-beam γ rays are from the by-products of ^{175}Re (4n channel), ^{174}W (p4n channel) and ^{171}Ta (α3n channel) in this experiment, and the high spin states of these nuclei have been well studied. So the rotational bands associated with Fig. 2 are considered to belong to ^{174}Re and a partial level scheme are

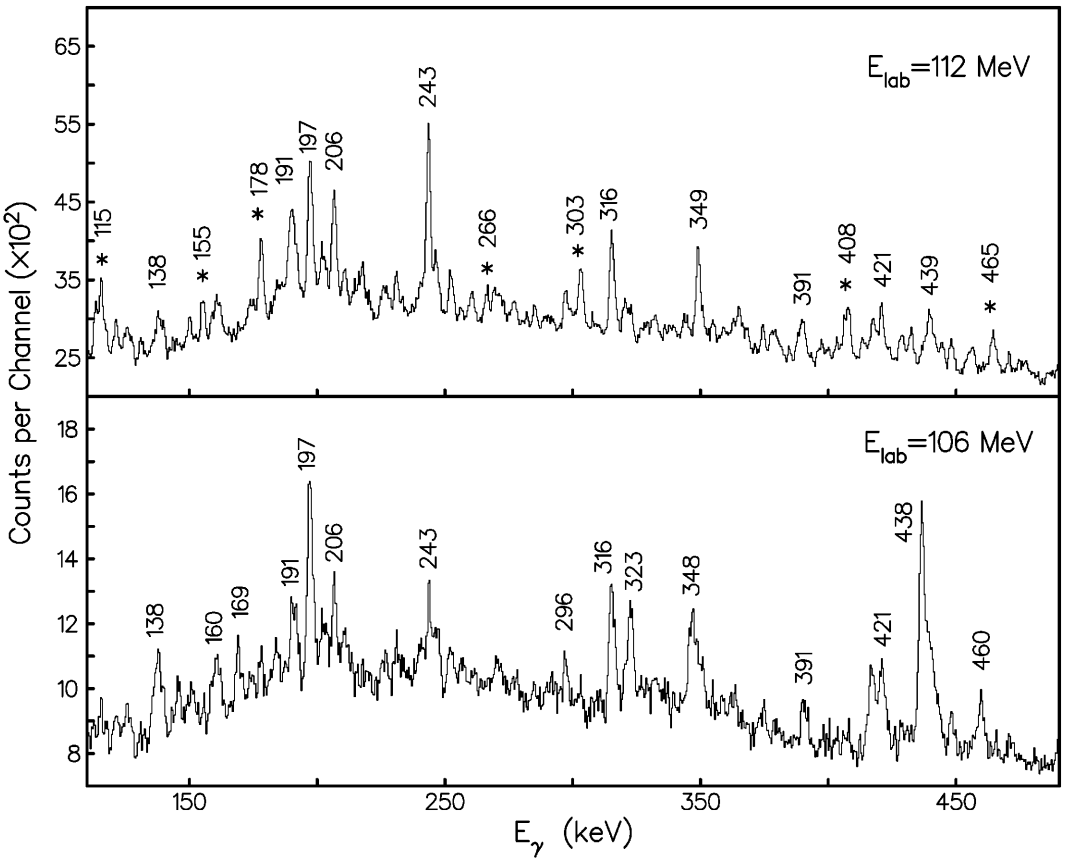

Fig. 1. γ-ray spectra obtained at the beam energies of 112 MeV (upper part) and 106 MeV (lower part). The peaks with "$\star$" indicate the in-beam γ rays from ^{174}Re

deduced and shown in Fig. 3, where the γ-transition energies are within an uncertainty of 0.5 keV. The ordering of γ transitions in each band is based on γ-γ coincidence relationships, γ-ray energy sums and γ-ray relative intensities.

The level scheme shown in Fig. 3 is largely different from that reported in [2]. First, the 197-315-421-512 keV... ΔI=2 cascade can be attributed to the $\pi 1/2^-[541]$ band of ^{175}Re by comparing the spectra in Fig. 1. Second, the whole ΔI=1 cascade in [2] can not be established from our data, however, part of this cascade can be assigned to either the $\pi 9/2^-[514]$ band or to the $\pi 5/2^+[402]$ band of ^{175}Re [3,4] with the observation of crossover transitions. Third, there is no coincidence relationship between the 303-keV and 177-keV lines. From our measurements shown in Fig. 1 and the K x-γ coincidences, we propose a partial level scheme of ^{174}Re presented in Fig. 3. It should be noted that the statistics of our data is poor, therefore, the further information related to the band structure (for example the DCO ratios and the in-band $B(M1)/B(E2)$ ratios) could not be extracted. The brief discussions given below are based mainly on the existed knowledge about the band structures of the odd-odd nucleus in this mass region.

We concentrate on the cascade shown in Fig. 2(a) which is considered to be the doubly decoupled band (band 1 in Fig. 3) based on the $\pi 1/2^-[541] \otimes \nu 1/2^-[521]$ configuration. The γ rays associated with this band is relatively strong in the total projection spectra. In fact, the $5/2^-$ member of $\pi 1/2^-[541]$ configuration and the intrinsic $\nu 1/2^-[521]$ state are considered to be the ground state or low-lying excited state in the neighboring ^{173}Re [6], ^{175}Re [3,4] and ^{173,175}W [7] nuclei. The band head with the $\pi 1/2^-[541] \otimes \nu 1/2^-[521]$ configuration could be the ground state or low-lying state of ^{174}Re (in a zero-order approximation [8] neglecting residual interaction), thus a rotational band based on it could be observed in this experiment. The same decoupled bands have been found in ^{176}Re [8] and ^{178}Re [9] and drawn in the left of Fig. 3 for comparison. The good systematics in level spacings suggests that the lowest level of this band is most probably the $I^\pi = (5)^+$ state. The γ-ray corresponding to the $5^+ \rightarrow 3^+$ transition in this band is probably out of the detection limit because of the lower transition energy and the higher internal conversion. The signature splitting in the doubly decoupled band is very large [1], only the favored $\Delta I = 2$ transition sequence (among the odd-spin levels) could be observed in this experiment; the unfavored one is higher-lying due to the decoupling effect and usually difficult to be observed. From Fig. 2(a) one can see clearly the backbending around $\hbar\omega_c$ =0.25 MeV which is close to the AB crossing frequency of yrast band in the neighboring even-even nuclei and consistent with the expectation [1].

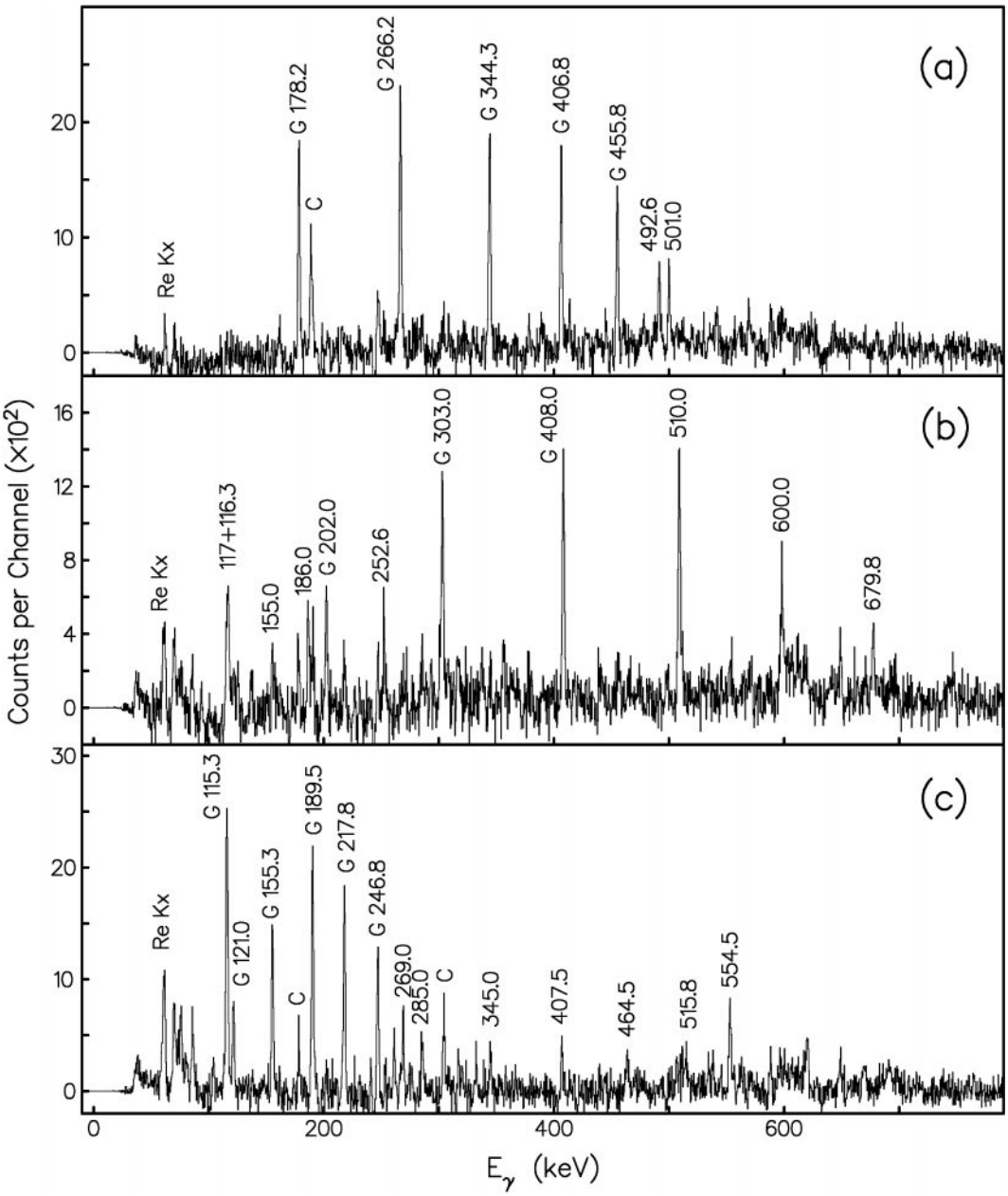

Fig. 2. Selected sum-gate spectra (a), (b), and (c) for band 1, band 2, and band 3, respectively. The mark "G" indicates gating γ ray, and "C" for contamination

Band 2 is most strongly populated in this experiment and can be regarded as the semidecoupled band [1] based on the $\pi 1/2^-[541](\alpha = 1/2)\otimes\nu i_{13/2}(\alpha = \pm 1/2)$ configuration. This assignment is supported by the pronounced level staggering and a large band crossing frequency $\hbar\omega_c \geq 0.34$ MeV [1]. The semidecoupled bands have been found in many odd-odd nuclei in this mass region (see, for example, [8, 10] and references therein), but, it was not until quite recently that firm spin assignments had been made in ^{162,164}Tm and ^{174}Ta [11]. As a consequence, the signature inversion has been discovered in the $\pi 1/2^-[541]\otimes\nu i_{13/2}$ semidecoupled bands. If the systematics in level spacings can be used, the spins of band 2 could be proposed as shown in Fig. 3. This spin assignment will consequently lead to a low spin signature inversion consistent with the systematics of level staggering pattern discussed in [8,10].

Apart from band 1 and band 2, we would like to report the observation of a strongly coupled band (band 3 in Fig. 3). This band shows intensive in-band $M1/E2$ transitions as indicated in Fig. 2(c) and is most likely based on the $\pi h_{11/2}(\alpha$quasiparticle configuration. This band can not be extended to higher spins, and the DCO ratios and the in-band $B(M1)/B(E2)$ ratios can not be extracted because of the poor statistics of our data. Another exper-

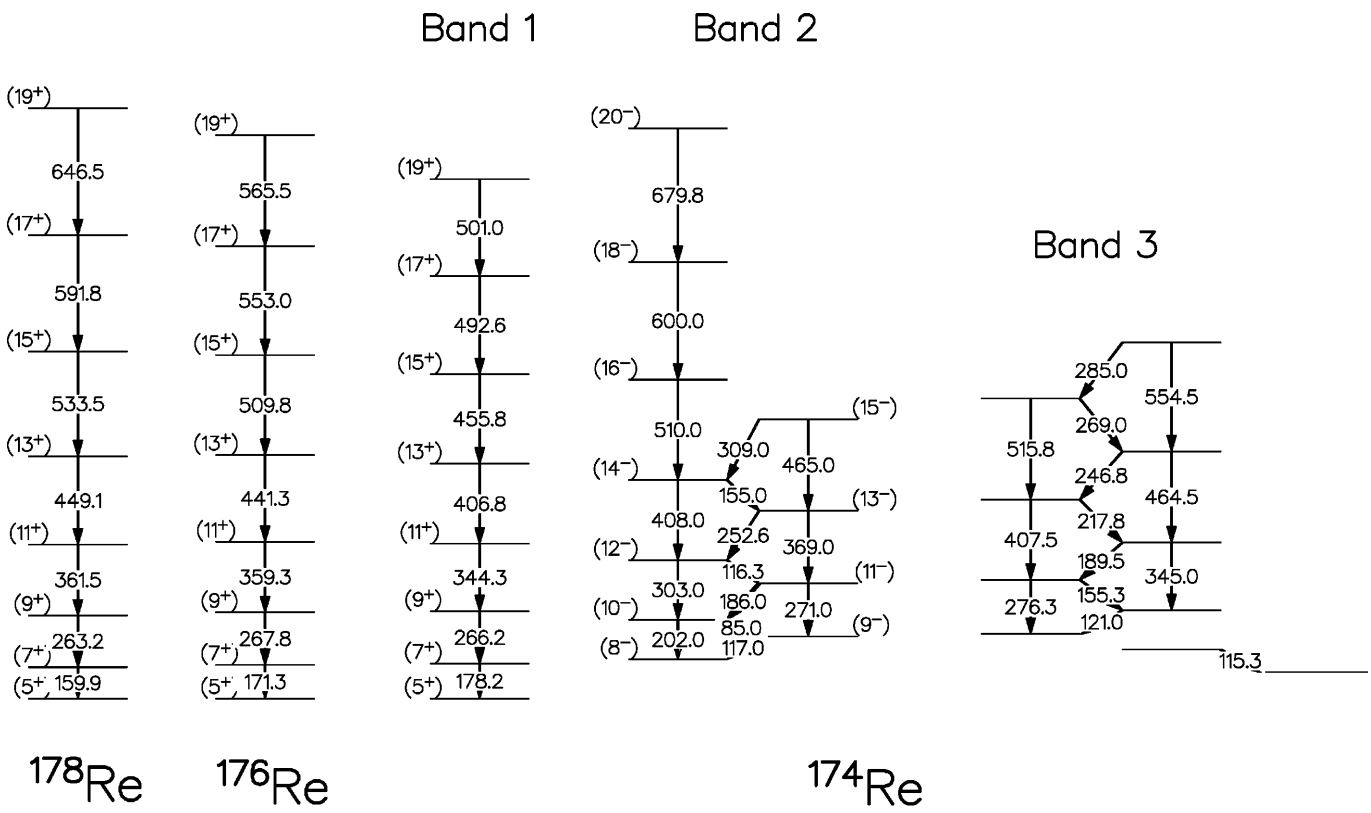

Fig. 3. Partial level scheme of ^{174}Re deduced from the present work

iment with high statistics is in plan to further study the band structures of ^{174}Re.

On summary, three rotational bands in odd-odd ^{174}Re have been newly identified by this work. The level scheme presented here is largely different from the previous one. The doubly decoupled band and the semidecoupled one are stressed in this paper.

The authors wish to thank the staffs in the accelerator division of IMP for providing the ^{20}Ne beam and Mrs. Wang Xiuying for preparing the ^{159}Tb target. This work has been supported partly by the Natural Science Foundation of China (grants Nos. 19605008, 19635030), "100 persons project" of CAS, and "95" significant project for basic research of CAS, respectively.

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