Rotational Bands in Odd-Odd ^{174}Re *

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Abstract High spin states in ^{174}Re have been studied via the ^{159}Tb (^{20}Ne, 5nγ) ^{174}Re reaction through excitation function, X-γ and γ-γ coincidence measurements. A stretched $E2$ cascade has been identified and assigned to be the doubly decoupled band based on the $\pi 1/2^-[541]\otimes\nu 1/2^-[521]$ configuration. Other two bands with semidecoupled and strongly coupled characters have been found and their quasiparticle configurations are qualitatively discussed.

Key words odd-odd nucleus, in-beam gamma ray, decoupled band

The concept of doubly decoupled band has been well established[1] in the deformed rear-earth nuclei. In such a band structure, both the valence proton and the valence neutron occupy predominantly the $\Omega = 1/2$ orbits, and as a consequence, the stretched $E2$ cascade similar to that of the yrast band of neighboring even-even nuclei has been experimentally identified. Four rotational bands of ^{174}Re have been previously reported in Ref. [2] using the ^{20}Ne + ^{159}Tb reaction at beam energy of 115 MeV. However, the assignment of these rotational bands to ^{174}Re has not been confirmed by the excitation function measurement[2]. After the report of reference [2], the level scheme of ^{175}Re has been established consistently by two groups[3,4]. It is surprising that the doubly decoupled band reported in Ref. [2] is almost the same as the $\pi 1/2^-[541]$ decoupled band in ^{175}Re. Furthermore, another $M1/E2$ γ transition sequence assigned to ^{174}Re[2] can also be found in the $\pi 5/2^+[402]$ band of ^{175}Re[3,4]. Therefore, it is worthwhile to reinvestigate the band structures and, in particular, to search for the doubly decoupled band in ^{174}Re.

The experiment has been performed at HIRFL using the ^{159}Tb (^{20}Ne, 5nγ) ^{174}Re reaction. The target is a natural ^{159}Tb metallic foil of 2 mg/cm^2 thickness with 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° and 90° 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 originating from ^{175}Re (4n channel) or from ^{174}Re (5n channel), the beam energies of 106 and 112 MeV were used during experiment. Two spectra are shown in Fig. 1 where γ rays coming from ^{175}Re (4n channel)[3,4] are dominant at 106 MeV beam energy, and some new γ rays (115, 155, 178, 303, and 408 keV) become stronger when the beam energy is increased to 112 MeV. The decay γ rays were also measured to check if ^{174}Re was produced at E_{lab} = 112MeV. 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 (± 0.10) minutes consistent with the $T_{1/2}$ = 2.42 (± 0.07) minutes of ^{174}Re

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evaluated in Ref. [5]. This result indicates that ^{174}Re was produced and therefore the coincidence measurement for ^{174}Re has been done at 112 MeV beam energy. A total of 40 millions coincidence events was accumulated. The data were sorted into a 4096 × 4096 matrix after gain matching for further analysis. Some typical gated spectra are presented in Fig. 2. The partial level scheme of ^{174}Re deduced from present work are shown in Fig. 3, where the γ-transition energies are within an uncertainty of 0.5 keV. The ordering of the transitions in the three bands of ^{174}Re is based on γ-γ coincidence relation, γ-ray energy sums and γ-ray relative intensities.

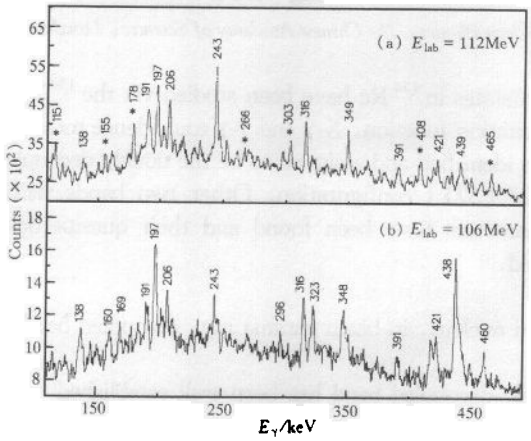

Fig. 1 γ − ray spectra obtained at the beam energies of 112 MeV (a) and 106 MeV (b). The peaks with ' * ' indicate the in − beam γ rays from ^{174}Re

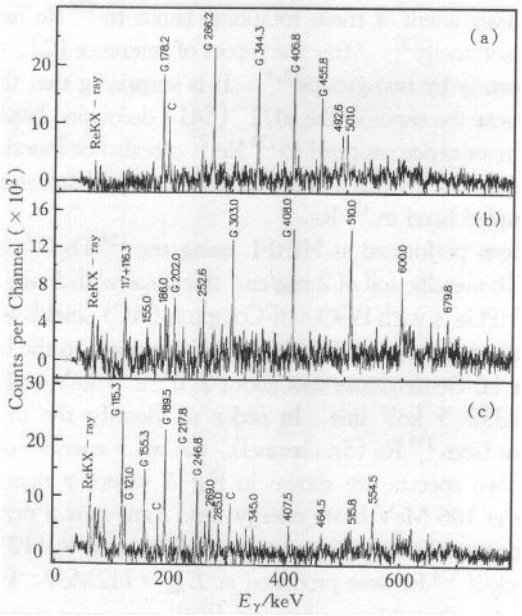

Fig. 2 Selected sum − gate spectra (a), (b) and (c) for band 1, band 2 and band 3, respectively. The mark 'G' indicates gating γ ray, and 'C' for contamination

The level scheme shown in Fig. 3 is largely different from that reported in Ref. [2]. First, the 197—315—421—512 keV⋯ $\Delta I = 2$ cascade can be attributed to the $\pi 1/2^-[541]$ band of ^{175}Re by comparing the spectra in Fig. 1. Second, the whole $\Delta I = 1$ cascade in

Ref. [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 relation between 303 keV and 177 keV lines. From our measurements shown in Fig. 1 and the KX − γ coincidences, we propose a partial level scheme of ^{174}Re in Fig. 3. Because of the poor statistic of our data, the detailed information (for example the DCO ratios and the in − band $B(M1)/B(E2)$ ratios) can not be extracted, therefore the brief discussions given below are based mainly on systematics.

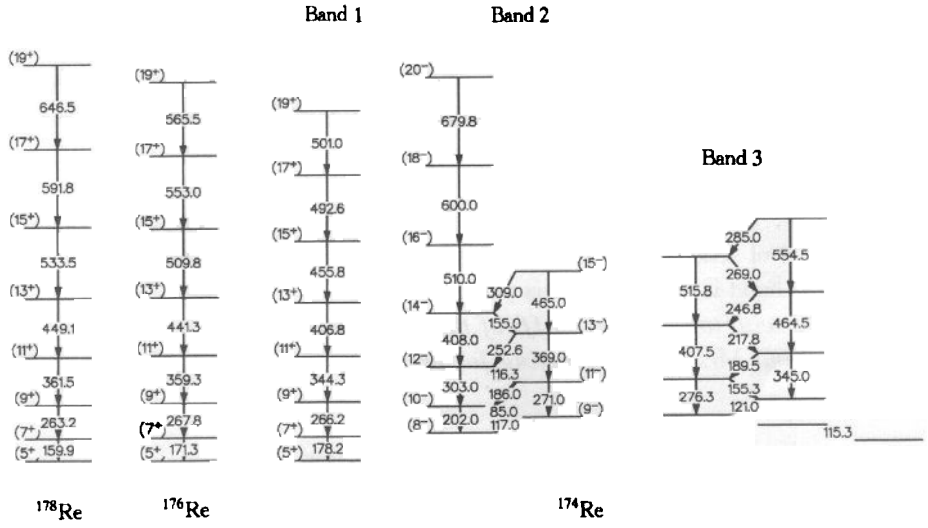

Fig. 3　Partial level scheme of ^{174}Re deduced from the present work

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 $\pi 1/2^-[541]\otimes\nu 1/2^-[521]$ configuration. As cited in the first paragraph, this structure involves both a proton and a neutron predominantly in $\Omega = 1/2$ orbits. The signature splitting in such a structure is very large, only the favored $\Delta I = 2$ transition sequence could be observed in this experiment, the unfavored one is usually difficult to be observed due to decoupling effect. 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 $\pi 1/2^-[541]\otimes\nu 1/2^-[521]$ 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 state of this band is most probably the $I^\pi = (5)^+$ state.

Band 2 is most strongly populated in this experiment and can be regarded as the semidecoupled band[1] based on $\pi 1/2^-[541]$ $(\alpha = 1/2)\otimes\nu i_{13/2}$ $(\alpha = \pm 1/2)$ configuration. This assignment is supported by the pronounced level staggering (originating from an $i_{13/2}$ neutron) and a large band crossing frequency $\hbar\omega_c \geq 0.34$ MeV (probably caused by both the neutron blocking effect and involvement of the proton $1/2^-[541]$ intruder orbit[10]. The semidecoupled bands have been found in many odd − odd nuclei in this mass region (see, for example,

Refs. [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 systematics.

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 intense in-band $M1/E2$ transitions as indicated in Fig. 2 (c) and is most likely based on the $\pi h_{11/2}(\alpha = \pm 1/2)\otimes\nu i_{13/2}(\alpha = 1/2)$ 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 poor statistic of the data. Another experiment 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 is stressed in this paper.

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奇奇核^{174}Re的转动带

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摘要 利用重离子熔合蒸发反应^{159}Tb (^{20}Ne, 5n)^{174}Re, 并通过激发函数、KX-γ和γ-γ符合测量, 研究了^{174}Re核的高自旋态. 鉴别并指定了^{174}Re核的一个基于$\pi 1/2^-[541]\otimes\nu 1/2^-[521]$准粒子组态上的双退耦带. 还发现了两个分别具有半退耦特征和强耦合特征的转动带,定性地讨论了它们的粒子组态.

关键词 奇奇核 在束γ线 退耦带

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