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Short note

Rotational bands in Odd-Odd ^{180}Ir

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Abstract. High spin states in ^{180}Ir have been studied via ^{154}Sm(^{31}P,5nγ)^{180}Ir reaction through excitation functions, X-γ and γ-γ-t coincidence measurements. Three rotational bands are identified including a doubly decoupled band, a semi-decoupled one, and a coupled structure up to (26^+). The quasiparticle configurations associated with these bands are suggested according to in-band $B(M1)/B(E2)$ ratios and band structures of neighboring odd-odd nuclei. Signature inversion in the semidecoupled band is discussed relying on systematics.

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

In a deformed odd-odd nucleus, a variety of coupling modes between the valence proton and neutron will result in a richness of band structures at moderate and high spins. Indeed, a general classification of the different coupling schemes has been proposed [1], leading to doubly decoupled, semidecoupled, and compressed structures. Very recently, an interesting phenomenon, so-called signature inversion [2], has been found in the $\pi 1/2^-[541] \otimes \nu i_{13/2}$ semidecoupled bands of ^{162,164}Tm, ^{174}Ta [3−5], and ^{176}Re [6] nuclei. It is thus interesting to investigate the band structures in lighter Ir; the features cited above can be tested. Prior to this work, no high-spin data of ^{180}Ir have been available in literatures. The ground state of ^{180}Ir was suggested to be $I^\pi = (4,5)^+$ according to the study of ^{180}Ir β^+/EC decay [7]. From ^{184}Au α-decay studies four low-lying excited states in ^{180}Ir were identified but without spin and parity assignments [8].

The experiment has been performed in Japan Atomic Energy Research Institute (JAERI) using ^{154}Sm(^{31}P,5nγ)^{180}Ir reaction. The ^{31}P beam was provided by the JAERI tandem accelerator. The target is an enriched ^{154}Sm metallic foil of 2 mg/cm^2 thickness with 5 mg/cm^2 Au backing. The excitation function was measured using ^{31}P beam from 150 MeV to 170 MeV with 5 MeV energy step. The beam energy of 160 MeV was used during X-γ and γ-γ coincidence measurements. A γ-ray detector array [9] including 12 HPGe's with BGO anti-Compton (AC) shields was used. Six of them have efficiency of 70% and others of 40% relative to 3″×3″ NaI. To obtain the DCO ratios, the detectors were divided into 3 groups positioned at 32^0, 58^0, and 90^0 with respect to the beam direction. About 240 million coincidence events were accumulated and sorted to a 4k×4k matrix. The typical energy resolution of the HPGe detectors was about 2.0∼2.4 keV at FWHM for the 1332.5 keV line. The singles γ spectrum in this experiment was very complex; the photon peaks were often doublets or contaminated by the residual radioactivities. In order to avoid these contaminations, coincidence mode was used during the excitation function measurements. Data analysis shows that some uncontaminated γ rays can be clearly separated and thus attributed to ^{179}Ir (6n channel) [10], ^{180}Ir(5n channel), or ^{181}Ir (6n channel) [11]. On the other hand, the coincidences with Ir K X-rays and the in-beam data of ^{179}Ir and ^{181}Ir help the identification of new rotational bands observed in this experiment.

Some typical gated spectra are presented in Fig. 1. The partial level scheme of ^{180}Ir deduced from present work is shown in Fig. 2, where the γ-transition energies are within an uncertainty of 0.5 keV. The ordering of the transitions of the three bands is based on γ-γ coincidence relationships, γ-ray energy sums and γ-ray relative intensities.

Band 1 is considered to be the doubly decoupled band [1] based on $\pi 1/2^-[541] \otimes \nu 1/2^-[521]$ configuration. This structure involves both a proton and a neutron predominantly in $\Omega = 1/2$ obitals. Because of large signature

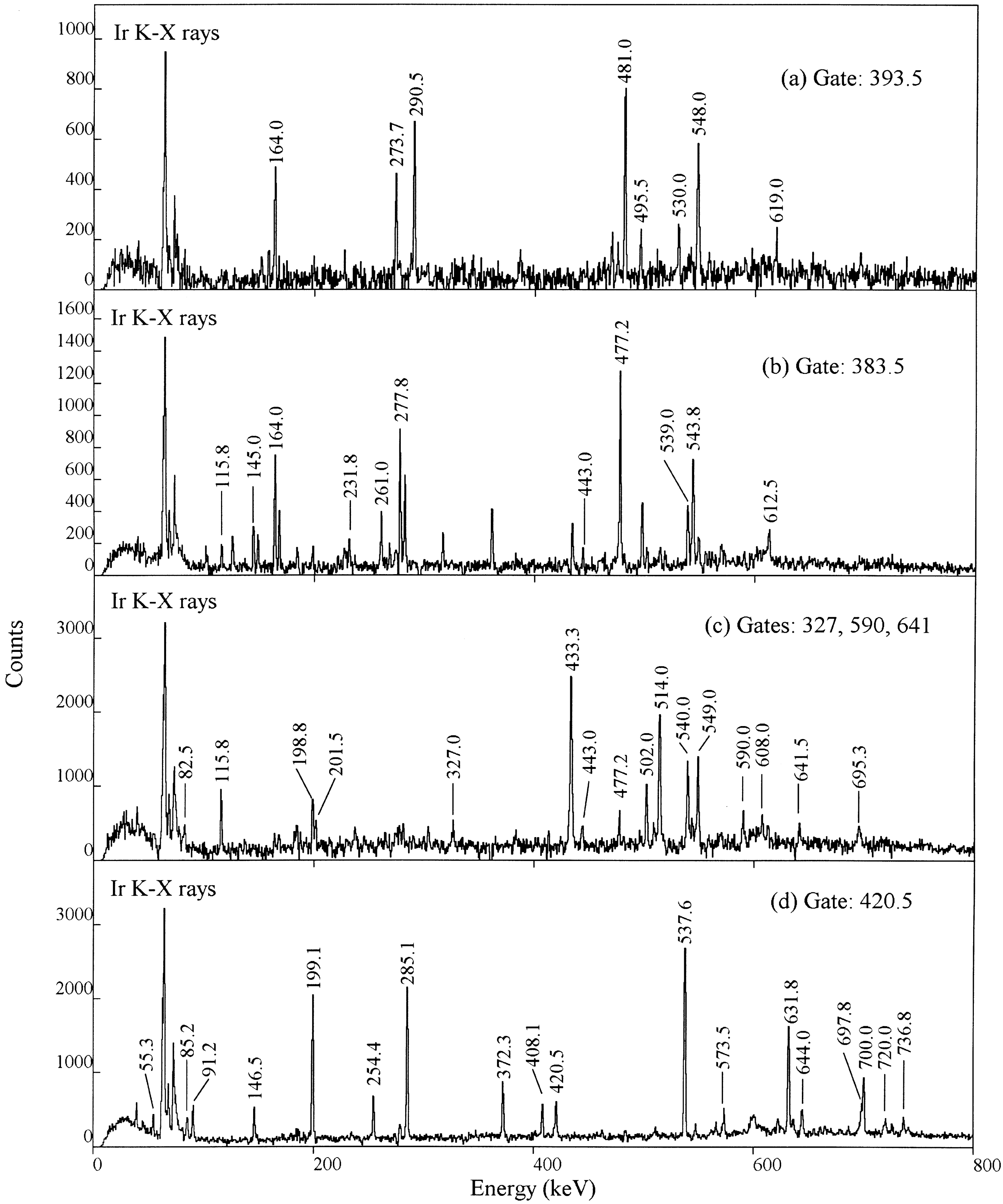

Fig. 1. Selected coincidence spectra. γ-rays belong to ^{180}Ir are indicated, the linking transitions are emphasized in (a) and (b). The contaminant peaks in (b) are from ^{179}Ir

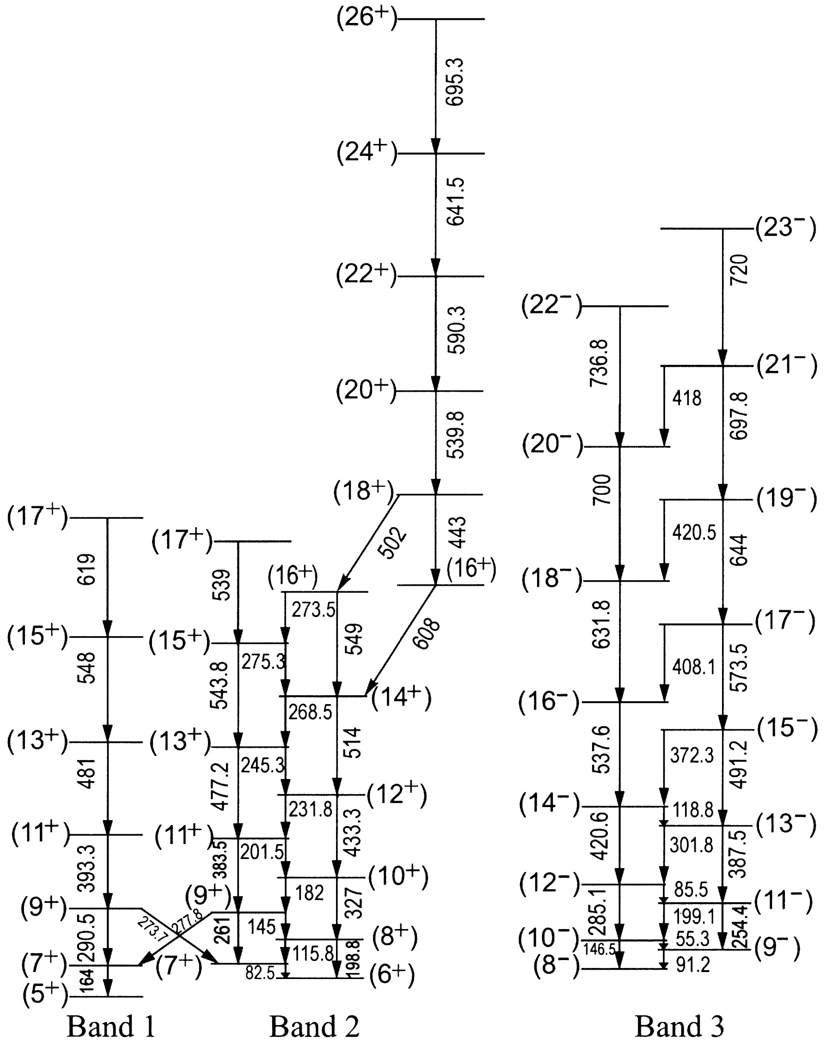

Fig. 2. Partial level scheme of ^{180}Ir deduced from the present work

splitting, the unfavored $\Delta I = 2$ transition sequences are normally difficult to observe. 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 in the neighboring ^{179}Ir [10], ^{181}Ir [11] and ^{179}Os [12] nuclei. A band head with the $\pi 1/2^-[541] \otimes \nu 1/2^-[521]$ configuration could be the ground state of ^{180}Ir (in a zero-order approximation [6] neglecting residual interaction), thus a rotational band based on it could be observed in this experiment. The same decoupled bands have been found in ^{178}Re [13] and ^{182}Ir [14]. The lowest state of this band is considered to be most probably the $I^\pi = (5)^+$ state according to the systematics.

Band 2 is a compressed band [1]. Two linking transitions (273.7 and 277.8 keV) between band 1 and 2 are clearly identified as shown in Fig. 1(a) and (b). Their DCO ratios are measured to be 0.95(10) and 1.08(10) respectively. Comparing with 0.47(10), 0.55(10) for 145, 115.8 keV lines, the linking transitions are considered to be stretched $E2$ transitions. The connections fix unambiguously spin and parity of band 2 relative to band 1. A sharp increase both in alignment and dynamic moment of inertia is observed at $\hbar\omega_c$=0.26 MeV, which is very close to the first band crossing frequency of $\nu 5/2^-[512]$ band in ^{179}Os [12]. The experimental $B(M1; I \to I-1)/B(E2; I \to I-2)$ ratios are extracted from in-band branching ratios by assuming pure M1 character for the $\Delta I = 1$ transitions; they are shown in Fig. 3, together with the theoretical predictions using formulae quoted in [15] for two possible configurations. Both Nilsson-model $g_K(5/2^-[512]) = -0.29$ and the measured $g_K(5/2^-[512]) = -0.17$ [12] values are used in the calculations. From this figure, the assignment of $\pi 1/2^-[541] \otimes \nu 5/2^-[512]$ configuration is the most probable. However another possibility of $\pi 1/2^-[541] \otimes \nu 7/2^-[514]$ configuration cannot be completely ruled out, because the $B(M1/B(E2)$ ratios are overestimated (the dashed line in Fig. 3) if the Nilsson-model g_K factor is used. On the other hand, the experimental $B(M1)/B(E2)$ values of $\nu 7/2^-[514]$ band in ^{179}Os show a gradual increase with spin and the extracted $g_K - g_R$ values are in the range of $-0.1 \sim -0.3$ [12]; if these values are used in the calculations, a gross agreement with data can also be obtained.

Band 3 is the most strongly populated band in this experiment and can be regarded as the yrast one based on $\pi 1/2^-[541](\alpha = 1/2) \otimes \nu i_{13/2}(\alpha = \pm 1/2)$ configura-

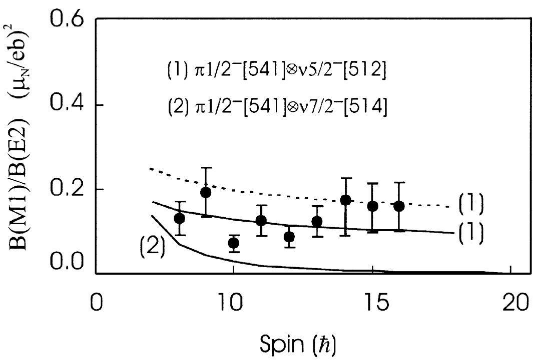

Fig. 3. Experimental $B(M1)/B(E2)$ ratios for band 2 and theoretical calculations for two possible configurations as indicated in the figure. Following parameters are used: $i_p = 3.5\ \hbar$, $g_K(p) = 0.7$, $g_R = 0.27$, $< K_p >= 0.5\ \hbar$, $Q_0 = 6.0\ b$ and (1) $i_n = 1\ \hbar$, $g_K(n) = -0.29$ (solid line), $g_K(n) = -0.17$ (dashed line),$< K_n >= 2.5\ \hbar$, $< K_{np} >= 2\ \hbar$ for $5/2^-[512]$ neutron and (2) $i_n = 1\ \hbar$, $g_K(n) = 0.26$, $< K_n >= 3.5\ \hbar$, $< K_{np} >= 4\ \hbar$ for $7/2^-[514]$ neutron

tion. This assignment is supported by the pronounced level staggering (originating from an $i_{13/2}$ neutron) and a large band crossing frequency $\hbar\omega_c$=0.35 MeV (probably caused by both the neutron blocking effect and involvement of the proton $1/2^-[541]$ intruder orbital) [16]. For some $\Delta I = 1$ transitions (199, 302, 372, and 408 keV lines), the DCO ratios are in the range of 0.4∼ 0.5, and the $B(M1)/B(E2)$ values scatter around 0.3 $(\mu_N/eb)^2$ which can be reproduced from calculations. The semidecoupled bands have been found in many odd-odd nuclei in this mass region (see, for example, [6] and references therein), but, it was not until quite recently that firm spin assignments had been made in ^{162,164}Tm and ^{174}Ta [3]. As a consequence, the signature inversion is discovered in the $\pi 1/2^-[541] \otimes \nu i_{13/2}$ semidecoupled bands. The relative position of band 3 is not known, since neither interband transitions nor transitions from this band to the ground state could be established in this work. Therefore the spin assignment cannot in principle be made by the usual spectroscopic methods. We would like to make a brief discussion based on systematics. The spins of the $\pi 1/2^-[541] \otimes \nu i_{13/2}$ band in ^{178}Re (the isotone of ^{180}Ir)

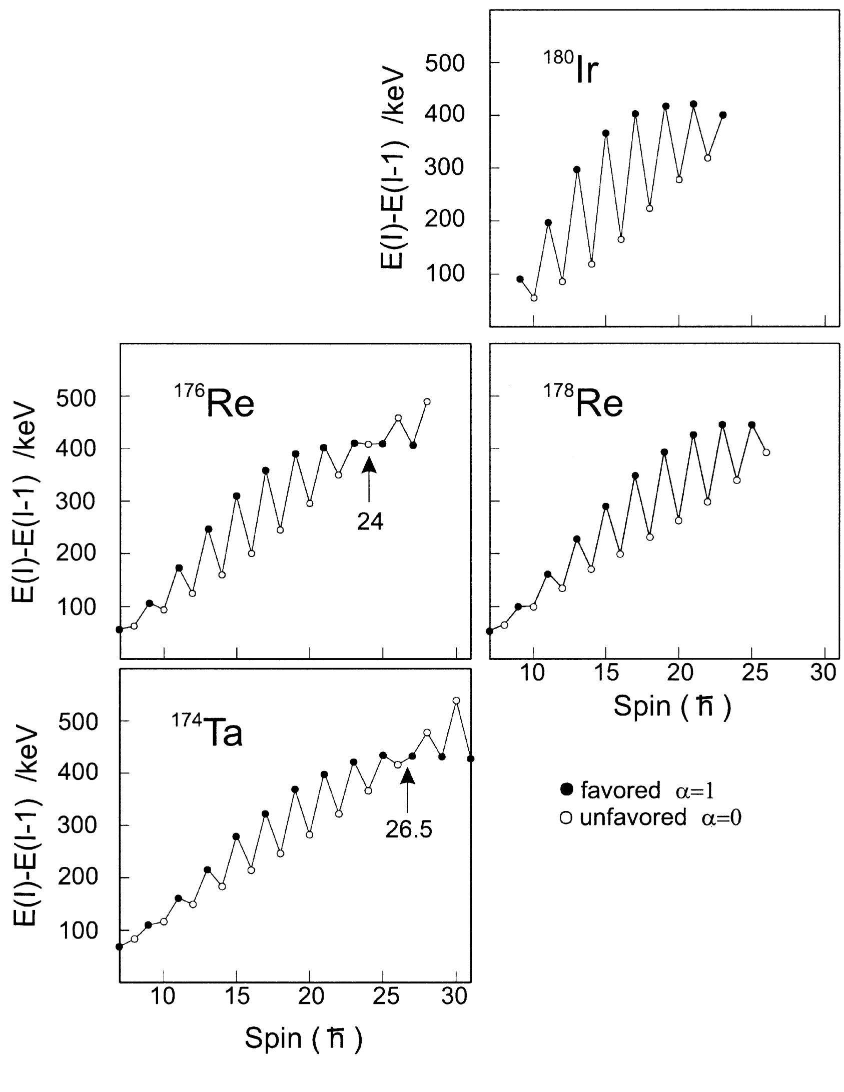

Fig. 4. Plot of level staggering for band 3 and semidecoupled bands in ^{174}Ta [3,4], ^{176,178}Re [6,13]

were proposed in [13], but changed in one unit in [6] leading to the good systematics both in level spacings and in the staggering pattern of energy levels. If the systematics in level spacings accepted and extrapolated to ^{180}Ir, the spin of lowest level in band 3 could be suggested to be (8^-) as indicated in Fig. 1. Consequently an inverted signature splitting occurs. The level staggering plot is shown in Fig. 4 in which a similar staggering pattern for N=101, 103 odd-odd isotones is evident. The levels with unfavored signature $\alpha = 0$ are lying lower than the favored ones at low spins for both series of isotones. The two signature sequences crosse at I=24, 26.5 in ^{176}Re and ^{174}Ta, respectively, and a similar tendency towards crossing in ^{178}Re and ^{180}Ir is clear at high spins as shown in the figure.

To summarize, three rotational bands in odd-odd ^{180}Ir have been newly identified which can be framed into the classification of different coupling schemes, say, doubly decoupled, semidecoupled, and compressed structures. The possible signature inversion in the semidecoupled band is suggested and discussed based on systematics. Firm spin assignment for this band is important to confirm our suggestion.

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