第26卷 第5期 高能物理与核物理 Vol.26, No.5
2002年5月 HIGH ENERGY PHYSICS AND NUCLEAR PHYSICS May, 2002

Signature Inversion Phenomena in the Rotational Bands of Odd-Odd ^{176}Ir *

ZHANG Yu-Hu[1] M. Oshima[2] Y. Toh[2] M. Koizumi[2] A. Osa[2] T. Shizuma[2]
T. Hayakawa[2] M. Sugawara[3] H. Kusakari[4] T. Morikawa[5] WEN Shu-Xian[6] ZHU Li-Hua[6]

1 (Institute of Modern Physics, The Chinese Academy of Sciences, Lanzhou 730000, China)
2 (Japan Atomic Energy Research Institute, Tokai-mura, Ibaraki 319 - 1195, Japan)
3 (Chiba Institute of Technology, Narashino, Chiba 275 - 0023, Japan)
4 (Chiba University, Inage-ku, Chiba 263 - 8512, Japan)
5 (Department of Physics, Kyushu University, Fukuoka 812 - 81, Japan)
6 (China Institute of Atomic Energy, Beijing 102413, China)

Abstract High-spin states in ^{176}Ir have been investigated via the ^{149}Sm(^{31}P,4nγ)^{176}Ir reaction through excitation functions, X-γ and γ-γ coincidence measurements. Four rotational bands have been identified for the first time and their configurations are suggested on the basis of the existing knowledge of band structures in odd-odd nuclei as well as the measured in-band B(M1)/B(E2) ratios. Among the four bands observed, the $\pi h_{9/2}\otimes\nu i_{13/2}$ and $\pi i_{13/2}\otimes\nu i_{13/2}$ bands exhibit an anomalous signature splitting. The signature inversion point is observed in the former at $I_c = 18\hbar$ which is consistent with expectations; this signature inversion spin in the $\pi i_{13/2}\otimes\nu i_{13/2}$ band may be larger than $25\hbar$.

Key words in-beam γ-spectroscopy, rotational bands in ^{176}Ir, signature inversion

Low-spin signature inversion[1] has been systematically observed throughout the chart of nuclides in the $\pi g_{9/2}\otimes\nu g_{9/2}$, $\pi h_{11/2}\otimes\nu h_{11/2}$, $\pi h_{11/2}\otimes\nu i_{13/2}$ and $\pi h_{9/2}\otimes\nu i_{13/2}$ configurations. Systematic analysis for the first three configurations has been done by Bermúdez and Cardona[2]. Analysis for the $\pi h_{9/2}\otimes\nu i_{13/2}$ structure shows that the critical spin I_c, at which the two $\Delta I = 2$ signature branches cross with each other, seems to decrease(increase) 2—3$\hbar$ while decreasing two neutrons(protons) for a chain of isotopes(isotones)[3]. If this regularity could be extended to a wide range of nuclei, one may expect to observe such an inversion spin around $I_c \approx 18\hbar$ in ^{176}Ir. On the other hand, the signature-inversion bands systematically investigated correspond to the high-j spherical parentage, it is thus a natural assumption that the $\pi i_{13/2}\otimes\nu i_{13/2}$ bands of high-j parentage may have similar inversion phenomenon; the $\pi i_{13/2}-\frac{1}{2}^{+}[660]$ orbital is involved instead of $\pi h_{9/2}-\frac{1}{2}^{-}[541]$ in the $\pi h_{9/2}\otimes\nu i_{13/2}$ structure[4]. With these points in mind, great efforts have been devoted recently to the studies of in-beam γ-ray spectroscopy in odd-odd ^{176,178}Ir and ^{182}Au. We concentrated on the observation of critical spin I_c in the $\pi h_{9/2}\otimes\nu i_{13/2}$ band; this could be regarded as an indirect evidence of signature inversion in spite of the uncertainties in spin assignment. Meanwhile much attention has been paid to establish the interband transitions from the expected $\pi i_{13/2}\otimes\nu i_{13/2}$ structure to a

Received 12 December 2001
* Supported by National Natural Science Funds for Distinguished Young Scholar (10025525), Major State Basic Research Development Program (G2000077400) and The Chinese Academy of Sciences

low-lying 2-quasiparticle band. We have noticed the fact that the $\frac{5}{2}^-\frac{1}{2}^-$ [541] levels are considered to be the ground states in ^{175,177}Ir, and the excitation energy of the $\pi i_{13/2}$ band member $\frac{13}{2}^+$ decreases from 0.807MeV in ^{177}Ir to 0.66MeV in ^{175}Ir[5] making it easier to observe the $\pi i_{13/2}\otimes\nu i_{13/2}$ band in ^{176}Ir. Prior to this work, no high-spin data on ^{176}Ir have been available in the literature[6]. Bosch et al. proposed[7] the spin and parity of 5^+ for the ground state of ^{176}Ir according to the intense β^+/EC feeding to the 6^+ rotational state in ^{176}Os. Preliminary results of this research subject have been reported in Refs. [3,8,9]. During the course of this investigation, Hojman et al. reported the observation of signature inversion in the $\pi i_{13/2}\otimes\nu i_{13/2}$ band in ^{178}Ir[10].

The experiment was performed at the Japan Atomic Energy Research Institute (JAERI). The ^{149}Sm(^{31}P,4nγ)^{176}Ir reaction was induced by a ^{31}P beam provided by the JAERI tandem accelerator. The target was an enriched ^{149}Sm metallic powder of 2.1mg/cm^2 thickness evaporated on to a 5.5mg/cm^2 Pb backing layer. A γ-ray detector array[11] comprising 11 HPGe's and one LOAX with BGO anti-Compton shields was used; the detectors were calibrated with ^{60}Co, ^{133}Ba, and ^{152}Eu standard sources; typical energy resolution was about 2.0—2.5keV at FWHM for the 1332.5keV line. In order to identify the in-beam γ rays belonging to ^{176}Ir, we measured an excitation function by varying the ^{31}P beam from 145MeV to 160MeV with 5MeV energy steps. At each beam energy, about 5×10^6—10×10^6 γ-γ coincidence events were accumulated and sorted on-line into a $4k\times4k$ matrix. By setting gates on the Ir K X-rays, we compared the relative intensities of γ rays emanating from ^{177}Ir and ^{175}Ir at various beam energies; numerous unknown γ rays were found to have comparable intensities as those of ^{177}Ir and ^{175}Ir, and therefore have been assigned to ^{176}Ir. Finally a beam energy of 155MeV was used for γ-γ coincidence measurement. About 350 million coincidence events were accumulated and sorted into a $4k\times4k$ matrix for off-line analysis. The relatively intense γ rays were from the fusion-evaporation residues of ^{175,176,177}Ir, ^{175,176}Os, and ^{173}Re corresponding to 5n, 4n, 3n, 4np, 3np and α3n evaporation channels, respectively. Fortunately, the detailed high-spin level schemes for ^{175,177}Ir, ^{175,176}Os and ^{173}Re are available. This information and the coincidences we measured with Ir K X-rays helped us assign new rotational bands in ^{176}Ir.

The partial level scheme of ^{176}Ir deduced from the present work is shown in Fig.1. The γ-transition energies in the level scheme are within an uncertainty of 0.5keV. The ordering of the transitions within the bands is established on the basis of γ-γ coincidence relationships, γ-ray energy sums and γ-ray relative intensities. No linking transitions have been observed from band 1 to bands 2, 3, and 4. The 97.8keV line, de-exciting the bandhead of band 2, exhibits the dipole character and is assigned to be an E1 transition based on the argument of intensity balance and measured DCO ratio. We tentatively placed the 97.8keV γ-ray to feed to the (7^+) level of band 3; no other interband transition between band 2 and band 3 could be identified. The connection between band 3 and band 4 has been established as shown in Fig.1 which fix unambiguously the spin and parity of one band relative to the other and thus facilitates their configuration assignments.

According to the classification of coupling scheme for odd-odd nuclei proposed by Kreiner et al.[12], and considering the fact that the $\pi1/2^-$[541], $\pi9/2^-$[514] and $\pi1/2^+$[660] bands in ^{175}Ir[5] and the $\nu1/2^-$[521], $\nu5/2^-$[512] and $\nu7/2^+$[633] bands in ^{175}Os[13] are strongly populated in the heavy-ion induced fusion-evaporation reactions, we propose the configurations of $\pi h_{9/2}(1/2^-[541])\otimes\nu i_{13/2}(7/2^+[633])$, $\pi h_{11/2}(9/2^-[514])\otimes\nu i_{13/2}(7/2^+[633])$, $\pi h_{11/2}(9/2^-[514])\otimes\nu 5/2^-[512]$, and $\pi i_{13/2}(1/2^+[660])\otimes\nu i_{13/2}(7/2^+[633])$ for bands 1, 2, 3, and 4, respectively. Indeed, the $\pi h_{9/2}\otimes\nu i_{13/2}$ and $\pi h_{11/2}\otimes\nu i_{13/2}$ bands have been identified in many odd-odd nuclei in

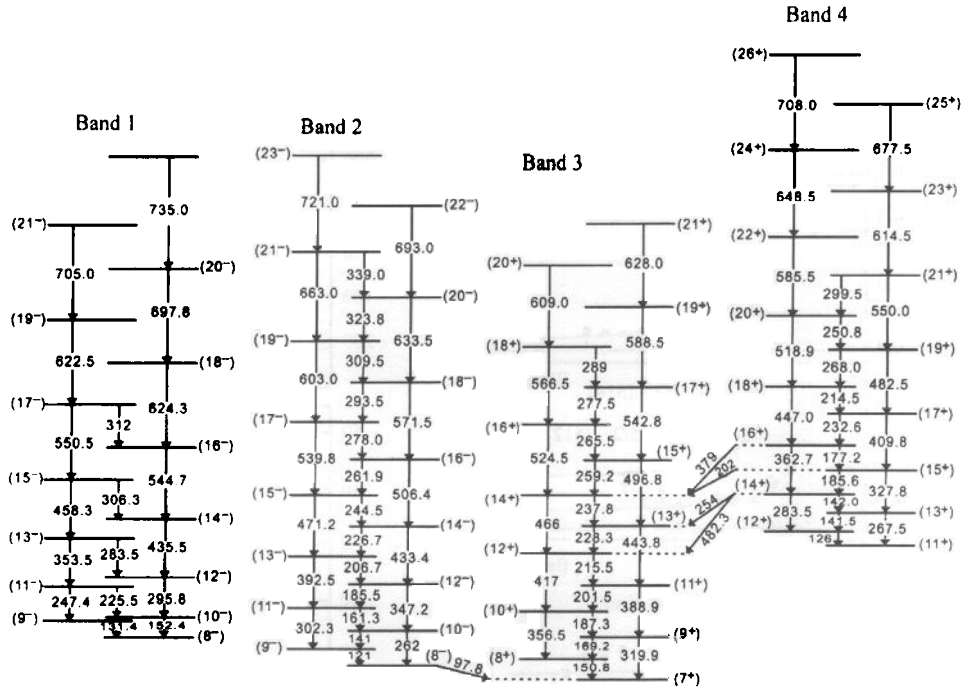

Fig.1.　Partial level scheme of ^{176}Ir deduced from the present work.

this region, and they exhibit very similar level spacings and decay patterns (e.g. in ^{176}Re[14] and ^{178}Ir[13]). Therefore the bandhead spins and parities are proposed to be $I_0^{\pi} = (8^-)$ for band 1 and $I_0^{\pi} = \Omega_p + \Omega_n = (8^-)$ for band 2 which are consistent with level spacing systematics. Band 3 have an effective $K_{eff} = (2 - X)/(X - 1) = 7.2$ (X is the energy ratio of first two in-band $\Delta I = 1$ transitions) close to the projection quantum number $K = \Omega_p + \Omega_n = 9/2 + 5/2 = 7$. This high value corresponds to a case in which both proton and neutron orbitals are weakly affected by the Coriolis interaction, resulting in $K_{eff} \approx K = \Omega_p + \Omega_n = 7$[15]. Consequently, the spin and parity for the lowest level of band 3 have been assigned to be $I_0^{\pi} = K = 7^+$. Based on the spin and parity assignments for band 3 and the observed linking transitions between band 3 and band 4, the spin and parity for band 4 can be fixed as shown in Fig.1. Fig.2 presents the experimental $B(M1)/B(E2)$ ratios for bands 1—4 together with the geometrical model calculations[14]. It is clear from this figure that the experimental $B(M1)/B(E2)$ ratios can be well reproduced under the assumption of the proposed configurations. It should be noted that the $\pi h_{11/2} \otimes \nu 5/2^-[512]$ and $\pi i_{13/2} \otimes \nu i_{13/2}$ bands in ^{178}Ir[8,10] and their connections have been observed showing similar level structures and decay patterns as the cases of bands 3 and 4 in ^{176}Ir.

Based on the configuration and spin-parity assignments, it is now interesting to point out that the signature splitting in the $\pi h_{9/2} \otimes \nu i_{13/2}$ and $\pi i_{13/2} \otimes \nu i_{13/2}$ bands of odd-odd ^{176}Ir is inverted at low and medium spins. To illustrate further the features of signature inversion, we compare the typical staggering curves $S(I) = E(I) - E(I-1) - \frac{1}{2}[E(I+1) - E(I) + E(I-1) - E(I-2)]$ vs I in Fig.3 for the $\pi h_{9/2} \otimes \nu i_{13/2}$ and $\pi i_{13/2} \otimes \nu i_{13/2}$ bands in ^{176}Ir. The similar staggering pattern is impressive, i.e., the $\alpha_f^{p,n} = \alpha_f^p + \alpha_f^n = \frac{1}{2} + \frac{1}{2} = 1$ favored signature branch (odd-spin sequence) lies

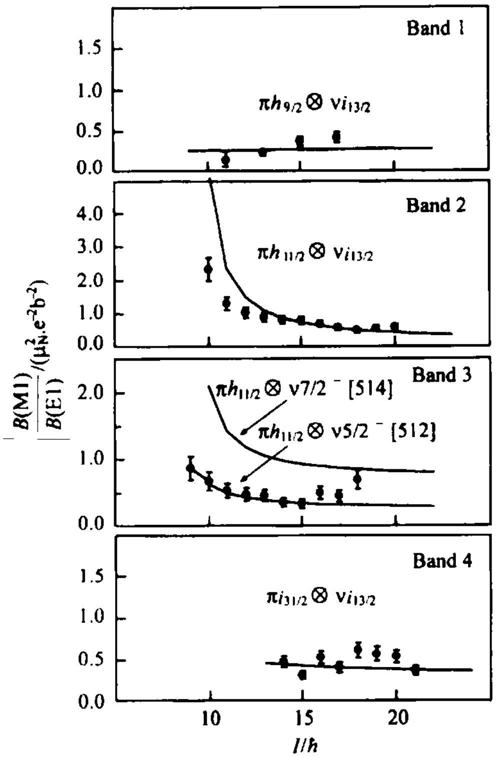

Fig.2. Experimental $B(M1)/B(E2)$ ratios and the geometric model calculations[3] under the assumptions of proposed configurations indicated on the pannel.

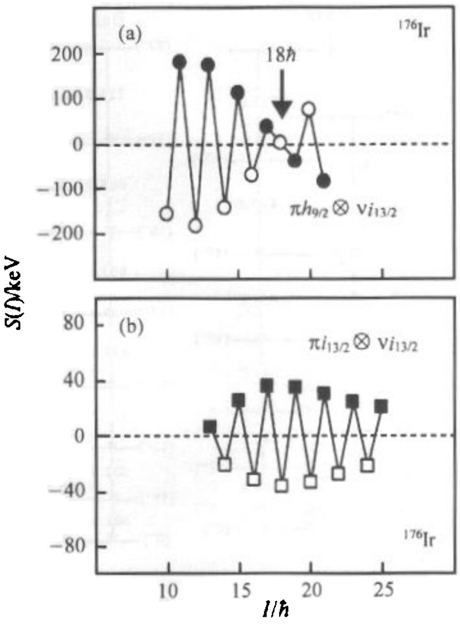

Fig.3. Plot of signature splittings $S(I)$ vs I for the $\pi h_{9/2}\otimes\nu i_{13/2}$ and $\pi i_{13/2}\otimes\nu i_{13/2}$ bands in ^{176}Ir. The arrow indicates the inversion spin.

higher than the $\alpha_{uf}^{p,n}=\alpha_f^p+\alpha_{uf}^n=\frac{1}{2}-\frac{1}{2}=0$ unfavored signature branch(even-spin sequence); this is the so-called low-spin signature inversion[1]. On the other hand, the signature splitting reverts to the normal ordering at $I_c=(18^-)$ for the $\pi h_{9/2}\otimes\nu i_{13/2}$ band in ^{176}Ir. This critical spin is $3\hbar$ lower than that in ^{178}Ir which is consistent with systematic expectations[3]. For the $\pi i_{13/2}\otimes\nu i_{13/2}$ band, the critical inversion spin has not been reached in this work, indicating that the critical spin I_c should be larger than $25\hbar$. The mechanism of such inversion phenomena in both the $\pi h_{9/2}\otimes\nu i_{13/2}$ and the $\pi i_{13/2}\otimes\nu i_{13/2}$ structures may be associated with, say, residual p-n interaction, positive γ, and quadrupole paring, etc., this is however beyond the scope of this paper. We would like to emphasize that the observation of such inversion phenomena in both ^{176}Ir and ^{178}Ir provides an interesting test ground for different theoretical interpretations.

The authors wish to thank the staffs in the JAERI tandem accelerator for providing ^{31}P beam and their hospitality during experiment.

References

1 Bengtsson R et al. Nucl. Phys., 1984, **A415**: 189

2 García Bermúdez G, Cardona M A. Phys. Rev., 2001, **C64**: 034311

3 ZHANG Y H et al. Eur. Phys. Jou., 2000, **A8**: 439
4 Bark R A et al. Phys. Lett., 1997, **B406**: 193
5 Dracoulis G D et al. Nucl. Phys., 1991, **A534**: 173
6 Browne E, Huo J. Nucl. Data Sheets, 1998, **84**: 337
7 Bosch U et al. Z. Phys., 1990, **A336**: 359
8 ZHANG Y H et al. Chin. Phys. Lett., 2001, **18**: 1323
9 ZHANG Y H et al. High Energy Phys. and Nucl. Phys., 2000, **24**(supp.): 21 (in Chinese)
(张玉虎等. 高能物理与核物理, 2000, **24**(增刊): 21)
10 Hojman D et al. Eur. Phys. J., 2001, **A10**: 245
11 Furuno K et al. Nucl. Instrum. Methods Phys. Res., 1999, **A421**: 211
12 Kreiner A J et al. Phys. Rev., 1987, **C36**: 2309
13 Fabricius B et al. Nucl. Phys., 1990, **A511**: 345
14 Cardona M A et al. Phys. Rev., 1999, **C59**: 1298
15 Hojman D et al. Phys. Rev., 1992, **C45**: 90

双奇核^{176}Ir转动带的旋称反转*

张玉虎[1]　M. Oshima[2]　Y. Toh[2]　M. Koizumi[2]　A. Osa[2]
T. Shizuma[2]　T. Hayakawa[2]　M. Sugawara[3]　H. Kusakari[4]
T. Morikawa[5]　温书贤[6]　竺礼华[6]

1 (中国科学院近代物理研究所　兰州　730000)
2 (Japan Atomic Energy Research Institute, Tokai-mura, Ibaraki 319 - 1195, Japan)
3 (Chiba Institute of Technology, Narashino, Chiba 275 - 0023, Japan)
4 (Chiba University, Inage-ku, Chiba 263 - 8512, Japan)
5 (Department of Physics, Kyushu University, Fukuoka 812 - 81, Japan)
6 (中国原子能科学研究院　北京　102413)

摘要　利用^{149}Sm(^{31}P,4nγ)反应,通过γ射线的激发函数测量、X-γ和γ-γ符合测量研究了双奇核^{176}Ir的高自旋态. 首次建立了双奇核^{176}Ir由4个转动带构成的能级纲图. 依据从实验数据中提取出的带内B(M1)/B(E2)值与理论计算值的比较,以及相邻双奇核的带结构特征,给出了转动带的准粒子组态. 基于本实验建立起的带间跃迁和在$I = 18\hbar$处观测到的旋称交叉,指出^{176}Ir核基于$\pi h_{9/2}\otimes\nu i_{13/2}$和$\pi i_{13/2}\otimes\nu i_{13/2}$组态的两个转动带在低自旋时出现旋称反转现象.

关键词　在束γ谱学　^{176}Ir的转动带　旋称反转

2001 - 12 - 12 收稿
* 国家杰出青年科学基金(10025525),国家重大基础研究发展规划(G2000077400)和中国科学院资助