Octupole Deformed Band and Quasi-γ Band in ^{146}Ce Nucleus*

CHEN Yong-Jing[1;1)] ZHU Sheng-Jiang[1] J. H. Hamilton[2] A. V. Ramayya[2] J. K. Hwang[2]
Y. X. Luo[2] J. O. Rasmussen[3] CHE Xin-Lai[1] DING Huai-Bo[1] LI Ming-Liang[1]

1 (Department of Physics, Tsinghua University, Beijing 100084, China)
2 (Department of Physics, Vanderbilt University, Nashville, Tennessee 37235 USA)
3 (Lawrence Berkeley National Laboratory, Berkeley, California 94720 USA)

Abstract High-spin structures in ^{146}Ce nucleus have been re-investigated by measuring the prompt γ rays from spontaneous fission of ^{252}Cf. The previously reported level scheme of ^{146}Ce has been updated. The octupole deformed collective bands have been extended up to higher spin states. A possible quasi-γ band structure was examined and reconstructed according to our data analysis. In addition, the reflection asymmetric shell model was applied to describe the octupole deformed bands in ^{146}Ce, and the calculated results are in good agreement with the experimental data at lower spins.

Key words high spin state, octupole deformed band, quasi-γ band, shell model

The nuclei in A=140 neutron-rich region have been studied very extensively in recent years. These neutron-rich nuclei have attracted continuing attention, since they can provide an opportunity to study the transition from the spherical structure near the N=82 closed to the deformed region beyond N=89. The ^{146}Ce nucleus with N=88, Z=58 is located at the onset of octupole deformation of the mass 140 region[1—3], and a detailed study of the level structures of this nucleus can provide important information on the nuclear shape changes and the octupole correlations in this region[4].

The experimental results of ^{146}Ce have been reported by several groups in the previous works. Wolf et al[5] measured γ-γ angular correlations on rather strong cascades in ^{146}Ce generated through the β-decay of the low-spin isomer of ^{146}La. In Refs. [6,7], the octupole deformed collective bands of ^{146}Ce have been established by measuring the prompt γ rays emitted by the fission fragments, and extended the high-spin states up to 11^- and 15^-, respectively. In an earlier paper[8], the quasi-γ band structure of ^{146}Ce has been suggested, but the members of the quasi-γ band were not clearly determined because the spins of those levels were not experimentally assigned. In publication[9], a possible quasi-γ band has been established and discussed through γ-γ angular correlation measurement. In this paper, we re-investigate the high spin states of ^{146}Ce from the prompt γ-ray studies in spontaneous fission of ^{252}Cf and report on the new results.

The experiment was carried out at the Lawrence Berkeley National Laboratory using a ^{252}Cf source of about 60μCi. The source was sandwiched between two Fe foils of thickness 10mg/cm^2. They were placed at the center of the Gammasphere array which, for this experiment, consisted of 102 Compton suppressed Ge detectors. The data were recorded in an

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1) E-mail: yj-chen@mail.tsinghua.edu.cn

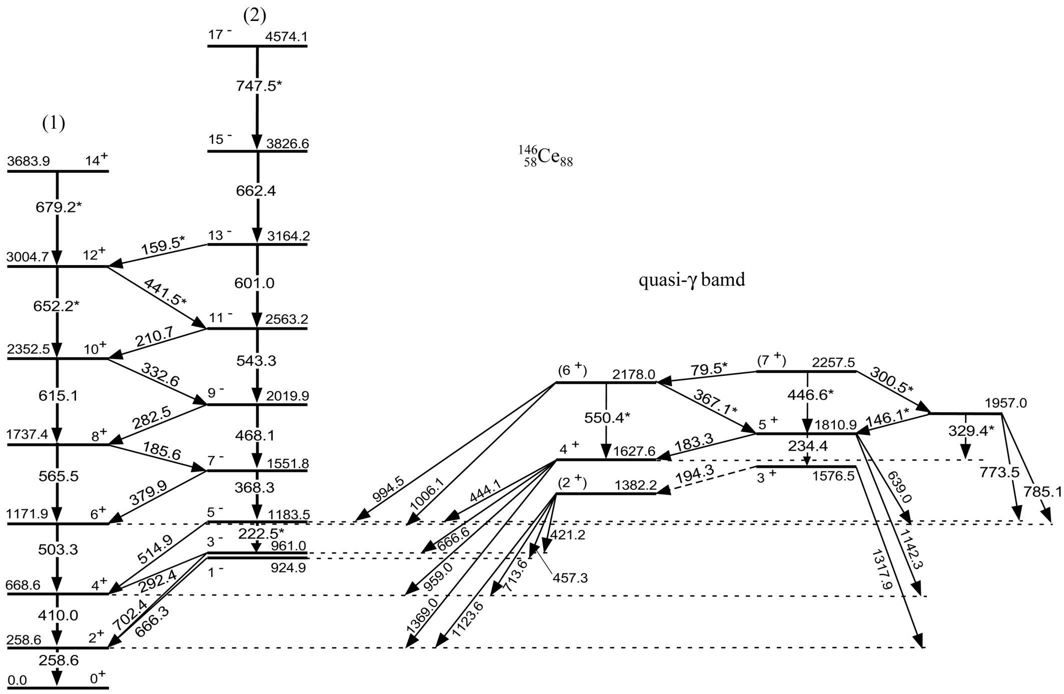

Fig. 1.　Partial level scheme of ^{146}Ce.

event-by-event mode. A total of 5.7×10^{11} triple or higher fold coincidence events were collected. The data were analyzed with the Radware software package[10] using γ-γ-γ coincidence method. Further experimental details can be found in Refs. [11—13].

The partial level scheme of ^{146}Ce constructed in the present work is shown in Fig. 1. The order of the transitions in the level in this figure has been determined by considering the previous works and the coincidence relationships between γ transitions. The new γ transitions observed in the present work are marked with an asterisk. The left part of this figure is the octupole deformed collective bands of ^{146}Ce nucleus, which are labeled as (1) and (2) on the top of the scheme. Comparing the present results with those in the Ref. [7], bands (1) and (2) have been extended and updated. For the band (1), we identified two new transitions of 652.2 and 679.2keV, and extended this band by two new levels 3004.7 and 3683.9keV with spins 12^+ and 14^+, respectively. For the band (2), we not only identified a new transition of 222.5keV at lower spins, which connected the 961.0 keV(3^-) level and the 1183.5keV(5^-) level, but also added a new 4574.1keV level along with a new transition of 747.5keV above it, with spin extended up to $17\hbar$. In addition, two new crossing transitions of 441.5 and 159.5keV between band (1) and band (2) were also identified. Fig. 2 shows a partial γ-ray coincidence spectrum obtained by double gating on the 503.3 and 565.5keV transitions in ^{146}Ce. Some already known transitions 258.6, 410.0, 615.1, 543.3, 601.0, 662.4, 282.5, 332.6 and 210.7keV reported in Ref. [7] have been seen in this coincidence spectrum, and the new transitions with energies 159.5, 441.5, 652.2, 679.2 and 747.5keV can been also seen. The partner transitions 151.8, 326.2 and 486.1keV in ^{102}Zr, as well as 212.6, 352.0 and 497.0keV in ^{100}Zr also can be seen clearly.

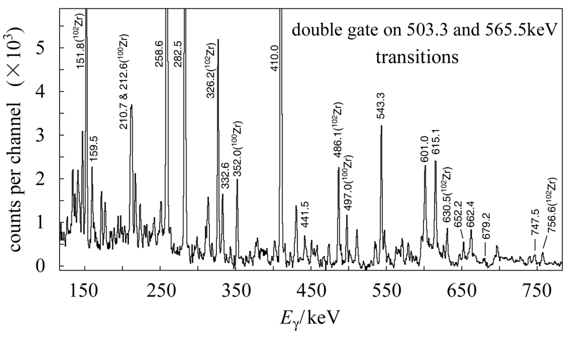

Fig. 2.　Partial coincidence spectrum obtained by double gating on 503.3 and 565.5keV transitions in ^{146}Ce.

Although a possible quasi-γ band (as shown in our Fig. 3) was proposed in Ref. [9], the members of quasi-γ band are not fully reasonable according to our present analysis. In the present work, we did not find the 1711.7keV(4^+) level, as well as the transitions 329.8keV (between 1711.7 and 1381.9keV levels) and 98.5keV (between 1810.2 and 1711.7keV levels) reported in Ref. [9]. We confirmed the 1810.9keV level (corresponding to the 1810.2keV level in Ref. [9]) and 1627.6keV level. They connected with the ground-state band by 639.0, 1142.3, 959.0, and 1369.0keV transitions, respectively.

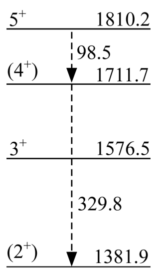

Fig. 3. The possible quasi-γ band proposed in ^{146}Ce from Ref. [9].

Between the 1810.9keV level and 1627.6keV level, we confirmed the strong transition of 183.3keV. Besides the 1627.6keV and 1810.9keV levels, we identified a new level at 2178.0keV. This new level connected with the ground-state band (1) by 1006.1keV transition and negative parity band (2) by 994.5 one. A new 550.4keV transition (between the 2178.0 and 1627.6keV levels) was identified. Between the 2178.0 and 1810.9keV levels, we identified a new 367.1keV transition. In Ref. [9], the spins and parities of 1627.6 and 1810.9keV levels were assigned as 4^+ and 5^+, respectively. Based on the above analysis, we concur with these assignments and propose tentative spin and parity for 2178.0keV level as 6^+. Above the 2178.0keV level, we also found a new level 2257.5keV. A strong transition of 446.6keV (between 2257.5 and 1810.9keV levels) and a weak transition of 79.5keV (between 2257.5 and 2178.0keV levels) were identified. Thus, we think that the possible spin and parity of 2257.5keV level is 7^+. The 1382.2 and 1576.5keV levels reported in Ref. [9] were also confirmed in this work, they are de-excited to the ground-state band by 713.6, 1123.6 and 1317.9keV transitions. The 1382.2keV level was assigned as a band head of the quasi-γ band in Refs. [8,14] with spin and parity of 2^+, and 1576.5keV level was assigned as the quasi-γ 3^+ state in Ref. [9]. We agree with these assignments. Between 1810.9keV and 1576.5keV levels, we confirmed the 234.4keV transition. A 194.3keV transition between 1576.5keV and 1382.2keV levels is not very clear in this work. Based on the above analysis, the levels of 1382.2(2^+), 1576.5(3^+), 1627.6(4^+), 1810.9(5^+), 2178.0(6^+) and 2257.5(7^+)keV were tentatively assigned as the members of a quasi-γ band, as shown in the right part of Fig. 1. In addition, we also identified a new level at 1957.0keV. This level connected with the quasi-γ band by 329.4, 146.1 and 300.5keV transitions, band (2) by 773.5keV transition and band (1) by 785.1keV transition. Fig. 4 shows the two partial γ-ray coincidence spectra obtained by gating on (a) 410.0 and 959.0keV, and (b) 258.6 and 410.0keV γ transitions, respectively. From Fig. 4(a), one can clearly observe the γ transitions 550.4, 367.1, 446.6, 79.5keV as well as the known transition 183.3keV which constructed the quasi-γ band. From Fig. 4(b), the main linking transitions between the quasi-γ band and bands(1) and (2) can be seen clearly, such as 959.0, 1142.3, 773.5, 785.1, 639.0, 994.5, and 1006.1keV transitions. Moreover one can see some transitions belong to bands (1) and (2) clearly.

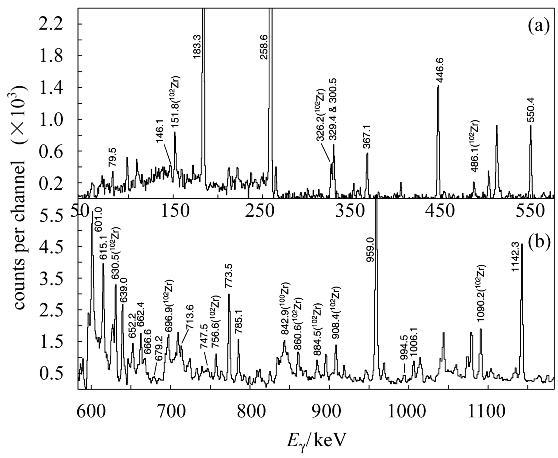

Fig. 4. Partial γ-ray coincidence spectra obtained by double gating on: (a) 410.0 and 959.0keV, (b) 258.6 and 410.0keV transitions in ^{146}Ce.

The octupole deformed bands of the ^{146}Ce nucleus can be calculated using the reflection asymmetric shell model (RASM) which was developed to describe the octupole deformed nuclei in recent years[15]. The RASM follows the basic philosophy of the standard shell model and the octupole coupling force is included in the Hamiltonian. It is an extension of the projected shell model[16] by including the parity projection in addition to angular momentum projection. Therefore, the calculated rotational bands have good angular momentum and good parity, and then can be directly compared with the experimental rotational bands. The RASM has successfully described the properties of the octupole deformed bands in Ra and Ba isotopes[15, 17]. The details about the RASM can be found in Ref. [15]. The deformation parameters used in the calculations are as follows: the quarupole ε_2, the octupole ε_3 and the hexadecapole ε_4 are 0.160, 0.083, and 0.03 for ^{146}Ce, respectively. The results of our calculations and comparison with the experimental data are shown in Fig. 5. It was found that the excitation energies of low-lying levels of ^{146}Ce could be fairly well reproduced by RASM calculation (although no overall agreement was obtained especially for higher-lying levels), and the large parity splitting at lower spins as well as the fast quenching of the parity splitting with increasing spin are also reproduced by the present calculation.

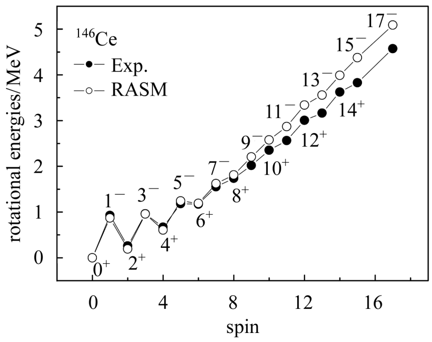

Fig. 5. Theoretical (open circle) and experimental (solid circle) energies of the octupole deformed bands of the ^{146}Ce nucleus as a function of spin.

In summary, the high-spin states in ^{146}Ce have been re-investigated by prompt γ-ray spectroscopy. The octupole deformed bands have been confirmed and expanded. A possible quasi-γ band structure are reconstructed. The octupole deformed bands in ^{146}Ce were calculated using the reflection asymmetric shell model, and the calculated results are in good agreement with the experimental data at lower spins.

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^{146}Ce核的八级形变带和准γ带*

陈永静[1;1)] 朱胜江[1] J. H. Hamilton[2] A. V. Ramayya[2] J. K. Hwang[2]
Y. X. Luo[2] J. O. Rasmussen[3] 车兴来[1] 丁怀博[1] 李明亮[1]

1 (清华大学物理系 北京 100084)
2 (Department of Physics, Vanderbilt University, Nashville, Tennessee 37235 USA)
3 (Lawrence Berkeley National Laboratory, Berkeley, California 94720 USA)

摘要 通过测量^{252}Cf自发裂变所产生的瞬发γ射线, 对^{146}Ce核的高自旋结构进行了重新研究, 结果更新了以前报道的能级纲图, 把八级形变集体带扩展到更高的自旋, 并且重新构建了可能的准γ带结构. 此外, 用反射不对称壳模型(RASM)对^{146}Ce核的八级形变带进行了计算, 低自旋处的计算结果与实验数据符合得很好.

关键词 高自旋态 八级形变带 准γ带 壳模型

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1) E-mail: yj-chen@mail.tsinghua.edu.cn