Some progress in research on octupole deformation around Z=56, N=88 nuclei*

ZHU Sheng-Jiang(朱胜江)[1;1)] WANG Jian-Guo(王建国)[1] CHEN Yong-Jing(陈永静)[1,4]
J. H. Hamilton[2] A. V. Ramayya[2] J. K. Hwang[2] J. O. Rasmussen[2] Y. X. Luo[2,3] K. Li[2]
CHE Xing-Lai(车兴来)[1] DING Huai-Bo(丁怀博)[1] LI Ming-Liang(李明亮)[1]
XU Qiang(徐强)[1] GU Long(顾龙)[1]

1 (Department of Physics, Tsinghua University, Beijing 100084, China)
2 (Department of Physics, Vanderbilt University, Nashville, TN 37235, USA)
3 (Lawrence Berkeley National Laboratory, Berkeley, CA 94720, USA)
4 (China Institute of Atomic Energy, Beijing 102413, China)

Abstract Recent progress in research on octupole deformation around Z=56, N=88 neutron-rich nuclei by our cooperative groups of Tsinghua University, Vanderbilt University and Lawrence Berkeley National Laboratory has been introduced. The experiment was carried out by measuring the prompt γ-rays in spontaneous fission of ^{252}Cf with the Gammasphere detector array. The new results of high spin states in ^{143}La and ^{148}Ce have been obtained and the octupole deformation bands are identified in both nuclei. The important structural characteristics have been discussed.

Key words high spin states, octupole deformation, neutron-rich nucleus

PACS 21.10.Re, 23.20.Lv, 27.60.+j

1 Introduction

Research on nuclear octupole deformation is an interesting subject. A nucleus with octupole deformation has reflection-asymmetric shape in its intrinsic frame. Theoretical calculations in the deformed shell model[1—3] indicated when a pair of single-particle orbitals with $\Delta n = 1$, $\Delta l = 3$, and $\Delta j = 3$ connected by large octupole interaction matrix elements, lie close to each other, strong octupole correlations occur. There exists an island of octupole deformed nuclei around Z=56, N=88 neutron-rich nuclear region. In octupole deformed nuclei, the level patterns are similar to rotational bands observed in reflection-asymmetric molecules including two bands of parity doublets characterized with simplex quantum numbers $s=\pm1$ in even-even nuclei and $s=\pm i$ in odd-A nuclei. The positive-and negative-parity rotational bands are interwined by strong $E1$ transitions. However, it is difficult to populate the high spin states of the neutron-rich nuclei by the heavy-ion reaction, an effective method is to measure the prompt γ-rays emitted from the fragments produced by the spontaneous fission[4—6]. In recent years, through international cooperation, we have identified and extended many octupole deformed band structures in this region, such as in ^{139}Xe[7, 8], in ^{140,141,142,143,145}Ba[7—10], in ^{144,146}Ce[11], in ^{145,147}La[12]. The neutron-rich ^{143}La

Received 8 July 2008
* Supported by National Natural Science Foundation of China (10575057, 10775078), Major State Basic Research Development Program (2007CB815005) and Special Program of Higher Education Science Foundation (20070003149). The work at Vanderbilt University, Lawrence Berkeley National Laboratory, are supported, respectively, by U.S. Department of Energy (DE-FG05-88ER40407, DE-AC03-76SF00098)
1) E-mail: zhushj@mail.tsinghua.edu.cn

and ^{148}Ce nuclei lie at the verge of this octupole deformed island. It is interesting to know whether the octupole deformed band structures exist or not in these two nuclei. In the previous reports, only some low excitation states have been identified in ^{143}La[13—15]. For ^{148}Ce, in our early report[6], the possible octupole band structure was briefly proposed. In more recent work, we have finished research on high spin states of ^{143}La and ^{148}Ce. Here we report on new results of the octupole deformed band structures in these two nuclei.

2 Experiment and results

The high spin states in ^{143}La and ^{148}Ce were investigated by measuring the prompt γ-rays emitted from the fragments produced in the spontaneous fission of ^{252}Cf. The experiment was carried out at the Lawrence Berkeley National Laboratory. The Gammasphere detector array which, for this experiment, consisted of 102 Compton-suppressed Ge detectors, was employed to detect the γ-rays. A total of 5.7×10^{11} triple- and higher-fold γ-coincidence events were collected. The data analysis was done at Tsinghua University.

The new level schemes of ^{143}La and ^{148}Ce obtained by our present work are shown in Figs. 1 and 2. They are deduced from γ-γ-γ coincidence relationships, γ-transition intensity analysis and total internal convention coefficient measurement. The collective bands are labeled on the top of the schemes.

For ^{143}La, in previous β-decay experiments[13—15], only two low excitation levels at 29.9 and 291.5 keV, along with three transitions of 29.9, 261.6 and 291.5 keV in Fig. 1 have been identified. We have identified 13 new levels and 20 new transitions in the present work. Three new collective bands have been established. In the previous work[13], the spin and parity (I^π) of ground state ^{143}La have been assigned as $7/2^+$, and the I^π's for 29.9 and 295.5 levels were assigned as $3/2^+$ and $5/2^+$, respectively. So the band (1) built on the 291.5 keV $5/2^+$ level should belong to a positive parity band with the $\Delta I=2$ stretched E2 transitions inside the band. According to the internal conversion coefficient measurement and systematic comparison with the structures of neighboring isotopes ^{145,147}La[12], the band (2) is assigned as a negative parity band. The total internal conversion coefficient ($\alpha_{\rm T}$) of the crossing transition 128.0 keV obtained in the present work is 0.16(5). So the 128.0 keV transition in ^{143}La has E1 multipolarity and the band (2) should be a negative parity band. The I^π for band (3) in ^{143}La can not be assigned in the present work.

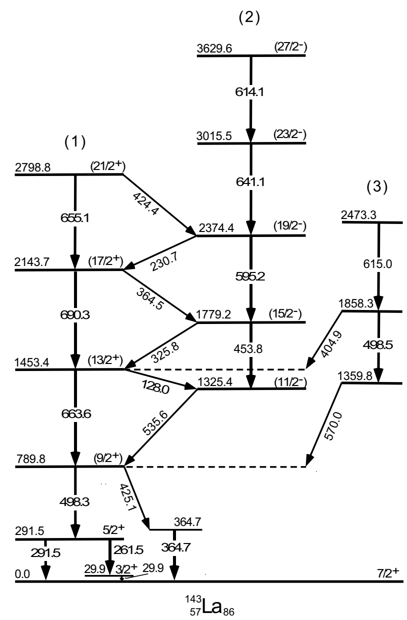

Fig. 1. Level scheme of ^{143}La.

In ^{148}Ce, 9 new levels and 20 new transitions have been identified comparing with our previous results[6], and 5 collective bands were established. The band (1) is a positive parity ground band which has been extended up to 22 $\hbar$. Based on comparing with the neighboring nuclei ^{144,146}Ce[11], the band (2) is assigned as a negative parity band. In the previous β-decay measurements[16], the I^π of 1117.6 keV level in band (3) have been assigned as 3^+, so we assigned the band (3) as a positive band. In order to determine the I^π of band (4), we have measured the $\alpha_{\rm T}$'s of three crossing transitions at 104.8, 108.6, 167.1 keV. The $\alpha_{\rm T}$'s for these transitions are 0.20(4), 0.16(4), 0.044(8), respectively. So above crossing transitions belong to $E1$ transitions and the band (4) is a negative parity band.

3 Discussion

From Figs. 1 and 2 one can see that three pairs of doublet bands, bands (1) and (2) in ^{143}La, bands (1) and (2) in ^{148}Ce, and bands (3) and (4) in ^{148}Ce belong to three typical octupole deformed band structures. In each octupole band structure, a set of positive- and negative-parity bands with the $\Delta I=2$

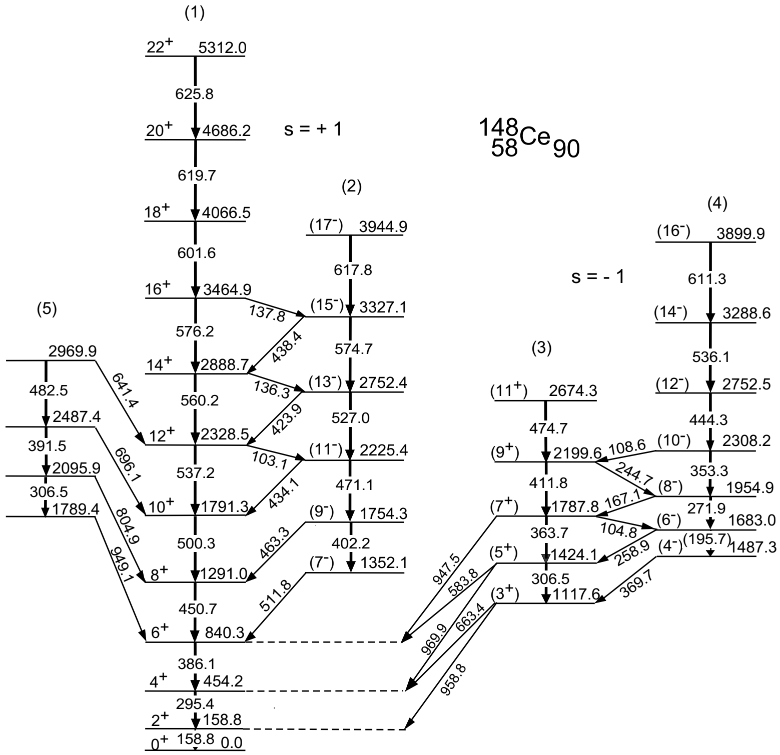

Fig. 2. Level scheme of ^{148}Ce.

E2 transitions in each band with the intertwined E1 transitions between these two bands. These band structures are similar to those observed in the neighboring nuclei[7—12]. In ^{143}La, the the octupole band structure has the simplex quantum number $s=+i$. In ^{148}Ce, the simplex numbers of two octupole band structures are $s=+1$ and $s=-1$, respectively. This type of double octupole band structures with $s=\pm1$ in ^{148}Ce is a first observation in this nuclear region.

In order to understand the octupole deformed character, we have made a systematic comparison of levels of the $s=+i$ band structure in ^{143}La with those in the neighboring isotope ^{145}La[12] as well as in the $N=86$ isotones ^{142}Ba[6] and ^{144}Ce[11], showing in Fig. 3. Form Fig. 3 one can see that the level structures in these octupole bands have similar character. However, the energies of the levels with the same spin in ^{143}La are higher than those in ^{145}La. These differences may be related to the different quadrupole deformation in both isotopes. But the level spaces in ^{143}La are closer to those in ^{142}Ba and ^{144}Ce isotones. This can be explained as the coupling of a single-particle or hole (proton) in ^{143}La with the core in neighboring nuclei ^{142}Ba and ^{144}Ce, as discussed in our previous paper[12]. We also made comparison of the levels in the $s=+1$ band structure in ^{148}Ce with those in ^{144,146}Ce, we found that they have similar structure character too.

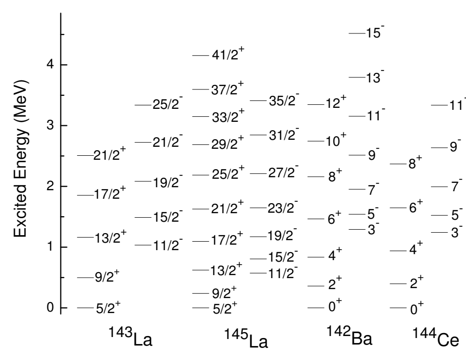

Fig. 3. Systematic comparison for the levels of s=+i band structures in ^{143,145}La and s=+1 band structures in ^{142}Ba and ^{144}Ce.

The B(E1)/B(E2) ratios in an octupole deformed band structure are important data. The values is defined as

$$\frac{B(\mathrm{E1})}{B(\mathrm{E2})}=0.771\frac{I_\gamma(\mathrm{E1})E_\gamma(\mathrm{E2})^5}{I_\gamma(\mathrm{E2})E_\gamma(\mathrm{E1})^3}(10^{-6}\mathrm{fm}^{-2}) \qquad (1)$$

where the intensity (I_γ) and energy (E_γ) have been taken from the present work. The average values of the B(E1)/B(E2) are 0.77, 0.82 and 1.51 (10^{-6}fm^{-2}) for $s=+i$ band structure in ^{143}La, $s=+1$ and $s=-1$ band structures in ^{148}Ce, respectively. The values observed in the neighboring nuclei are 1.0, 0.7, 0.76, 0.58 (10^{-6}fm^{-2}) for ^{142}Ba, ^{144}Ba, ^{145}La, and ^{147}La[9, 12], respectively. So the results of the ^{143}La and ^{148}Ce are comparable with those in the neighboring nuclei. This similarity indicates that the octupole correlations in ^{143}La and ^{148}Ce are strong. One the other hand, in ^{148}Ce the octupole correlations of $s=-1$ band structure are stronger than that of $s=+1$ band structure.

Plots of the moment of inertia (J_1) versus rotational frequency ($\hbar\omega$) for the $s=+i$ band structures in ^{143,145}La, $s=+1$ band structure in ^{146,148}Ce and $s=-1$ band structure in ^{148}Ce are shown in Figs. 4 and 5, respectively. From Fig. 4, one can see that the back-bendings (band crossings) appear in both bands of the $s=+1$ band structures around 0.25—0.30 MeV in ^{145}La. In ^{143}La, we can also see the back-bendings. Because the lower fission yield in ^{143}La than in ^{145}La in the spontaneous fission of ^{252}Cf, we can not observe the higher spin states, so the full back-bendings in ^{143}La can not be seen. However from Fig. 4, we can see that the back-bendings begin around 0.30—0.35 MeV in ^{143}La. As the back-bendings were explained by the alignment of a pair of neutrons in ^{145}La[12], so the back-bendings of ^{143}La may be caused by the alignment of a pair of neutrons too. This interpretation is reasonable as the alignment corresponding to two protons is blocked by the odd proton. From Fig. 5, one can see that in ^{146}Ce and ^{148}Ce the J_1 values of the negative-parity bands are much larger than those in the positive-parity bands at low $\hbar\omega$ values in each pair of the parity doublet bands. When the $\hbar\omega$ increases, they come close to each other. In the s=+1 band structure of ^{148}Ce, two curves cross at $\hbar\omega$ ~0.28 MeV. The smoothly increasing trends of J_1 with $\hbar\omega$ for the $s=+1$ bands in ^{148}Ce and ^{146}Ce are similar. But the J_1 of the negative parity band of the $s=-1$ band structure in ^{148}Ce is different from the others. It smoothly decreases with the increasing of the $\hbar\omega$. This structural feature calls for more theoretical work.

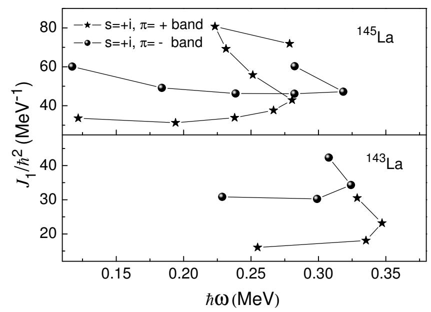

Fig. 4. Plots of moment of inertia (J_1) versus rotational frequency ($\hbar\omega$) for the $s=+i$ band structures in ^{143,145}La.

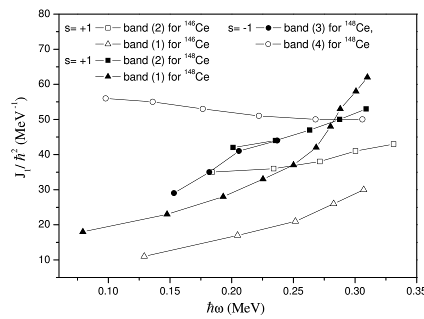

Fig. 5. Plots of moment of inertia (J_1) versus rotational frequency ($\hbar\omega$) for the $s=+1$ band structures in ^{146,148}Ce and $s=-1$ band structure in ^{148}Ce.

4 Summary and concluding remarks

The recent progress in research on octupole deformation around Z=56, N=88 neutron-rich nuclei by our cooperative groups has been introduced. Through measuring the prompt γ-rays from the spontaneous fission of ^{252}Cf, octupole deformed band structures in neutron-rich odd-A ^{143}La and even-even ^{148}Ce nuclei have been investigated. The $s=+i$ octupole band structure in ^{143}La and the $s=\pm1$ doublet octupole band structures have been identified. The important characteristics of these octupole band structures have been discussed.

References

1 Nazarewicz W et al. Phys. Rev. Lett., 1984, **52**: 1272
2 Nazarewicz W, Olanders P. Nucl. Phys. A, 1985, **441**: 420
3 Leander G A et al. Phys. Lett. B, 1985, **152**: 284
4 ZHU S J. Trends in Nucl. Phys.-Chinese Edition, 1992, **9**(24): 199
5 ZHU S J et al. Phys. Rev. C, 2000, **62**: 044310
6 Hamilton J H et al. Prog. Part. Nucl. Phys., 1995, **35**: 635
7 ZHU S J et al. J. Phys. G, 1997, **23**: L77
8 LUO Y X et al. Phys. Rev. C, 2002, **66**: 014305
9 ZHU S J et al. Phys. Lett. B, 1995, **357**: 273
10 ZHU S J et al. Phys. Rev. C, 1999, **60**: 051304(R)
11 ZHU L Y et al. High Energy Phys. and Nucl. Phys.-Chinese Edition, 1997, **22**: 885
12 ZHU S J et al. Phys. Rev. C, 1999, **59**: 1316 316
13 Faller S H et al. Phys. Rev. C, 1988, **38**: 307
14 Pacer J C et al. Phys. Rev. C, 1978, **17**: 710
15 Schussler F et al. Z. Phys. A, 1979, **290**: 359
16 Gill R L et al. Phys. Rev. C, 1983, **27**: 1732