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EC/β^+ decay of six medium-heavy nuclei

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Abstract Previous experimental results of (EC+β^+) decay for the medium-heavy nuclei reported by our group since 1996, including ^{153}Er, ^{157}Yb, ^{209}Fr, ^{128}Ce, ^{130}Ce, and ^{128}Pr have been briefly summarized. The observed low-lying states in their daughter nuclei have been reviewed in a systematic way and compared with different model calculations. Finally, some questions have been put forward for further study and discussion.

Key words (EC+β^+) decay, low-lying states, nuclear shape, multiplet, Gamow-Teller transition

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1 Introduction

Study of EC/β^+ decay is an important approach to investigate the nuclear structure in low-lying region. The Gamow-Teller transition is the major decay mode of neutron-deficient medium-heavy nuclei. In medium-heavy mass region, especially in the rare-earth region the nuclear shape changes rather complicatedly. Therefore, proposed EC/β^+ decay scheme could provide important information not only for nuclear shape and related structure in the region, but also for Gamow-Teller transition itself.

Our group has observed EC/β^+ decays for ^{153}Er, ^{157}Yb, ^{209}Fr, ^{128}Ce, ^{130}Ce, and ^{128}Pr, and proposed decay schemes for all of them[1—5] since 1996. The aimed nuclei were produced via the fusion evaporation reactions induced by heavy ions ^{16}O and ^{36}Ar, which were provided from a Sector Focused Cyclotron at the Institute of Modern Physics, Lanzhou, China. We used a He-jet fast tape transport system to move the reaction products to a shielded counting room, where the X-γ-γ-t coincidence measurements were carried out. In addition, the X-γ coincidence measurements were also used for Z identification. Sometimes, the excitation-function measurements were used for mass identification. In this paper we simply summarize the proposed decay schemes, make a systematic review to the observed low-lying states in the daughter nuclei, and compare the obtained physical results with different model calculations. Finally, some questions are put forward for further study and discussion.

2 Results and discussion

2.1 Even(Z)-odd(N) nuclei

From the EC/β^+ decay scheme of ^{153}Er, we found single particle states $s_{1/2}$, $d_{3/2}$ and maybe $d_{5/2}$ as well as a three quasi-particle state in the low-lying region of the daughter nucleus ^{153}Ho, while in the EC/β^+ decay scheme of ^{157}Yb we found a rotational band in the low-lying region of the daughter nucleus ^{157}Tm[1]. The Fig. 4 of the Ref. [1] is the systematic behavior of some characteristic low-lying states in the odd-A Tm(Z=69) and odd-A Ho(Z=67) isotopic chains with N = 82—90, and shows that the single particle states dominant the low-lying region in the isotopes with N = 82—86, while the rational bands dominant the low-lying region in the isotopes with N = 88 and 90.

This fact indicates that the transition point from near-spherical ground state to deformed ground-state appears between N = 86 and 88 in the two odd-A isotopic chains. However, as J. H. Hamilton[6] pointed out, a sudden onset of deformation happens between N = 88 and 90 in the even-even isotopic chains around the weak Z = 64 spherical shell region,

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such as Sm(Z=62), Gd(Z=64) and Dy(Z=66). The two-neutron shift for the transition point from Odd-A isotopic chain to Even-Even isotopic chain probably due to the paring effect which tends to maintain the spherical shape of nuclear ground state. The predicted deformation as a function of neutron number for the element Dy, Ho and Er is shown in Fig. 1. It can be seen in Fig. 1 that a sudden change of the nuclear deformation happens between N = 84 and 86. The theoretical predictions were given by Möller et al based on their macroscopic-microscopic model[7], and not consistent with both experimental results. So far we do not know what the reason behind the inconsistency is.

2.2 Odd(Z)-even(N) nucleus

The EC/β$^+$ decay scheme of ^{209}Fr was proposed by our group[2] in 1996. The branching ratio of the EC/β$^+$ decay of ^{209}Fr is as weak as 3%. Based on the decay scheme we found a multiplet, i.e. a five-fold state [(^{210}Rn 2$^+$)($\nu f_{5/2}$)$^{-1}$] in the low-lying region of the daughter nucleus of ^{209}Rn. Here, the (^{210}Rn 2$^+$) stands for the 2$^+$ vibration state of the core ^{210}Rn, while the ($\nu f_{5/2}$)$^{-1}$ stands for the neutron hole at the orbital $f_{5/2}$. There are 123 neutrons in ^{209}Rn. The last neutron in ^{209}Rn locates at the orbital 5/2[503]. The analogical structure of low-lying states in the N=123 isotone chain is shown in Fig. 2. The similar multiplet, which consists of a 2$^+$vibrational state of the core and the neutron hole at the orbital of $f_{5/2}$, can be seen at the low-lying region not only in ^{209}Rn(Z=86), but also in ^{207}Po(Z=84) and ^{205}Pb(Z=82). However, we are not able to reproduce the systematics by a shell model calculation yet.

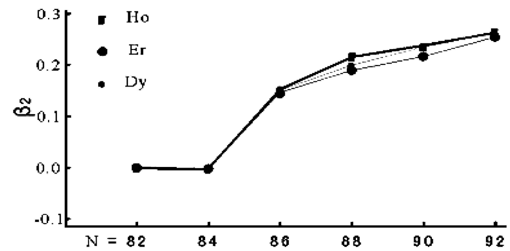

Fig. 1. Predicted deformation β_2 as a function of neutron number for the element Dy, Ho and Er.

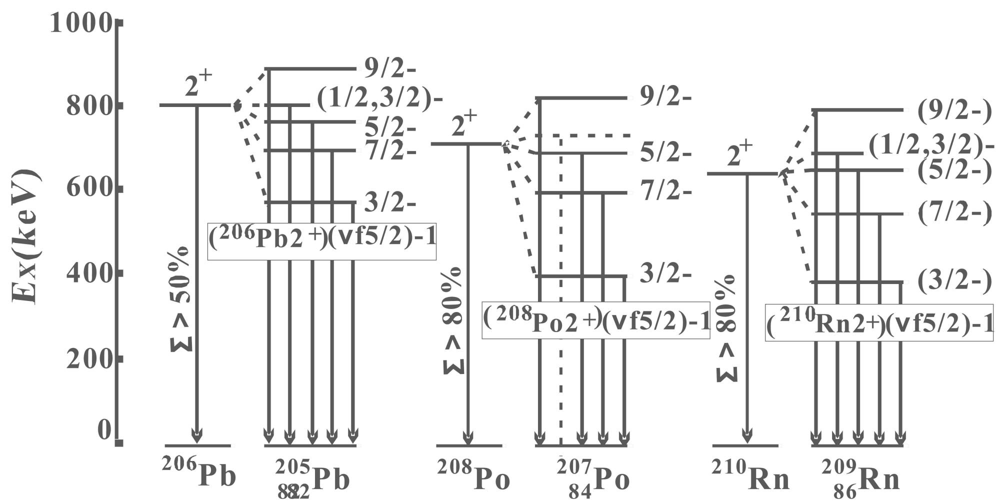

Fig. 2. Analogical Structure of low-lying states in the isotone chain with N = 123.

2.3 Even-even nuclei

The EC/β$^+$ decay scheme of ^{130}Ce was proposed by our group in 1996[3], and evaluated and edited in Nuclear Data Sheets by Singh et al in 2001[8]. The experiment was carried out very carefully. The energy of γ line was searched up to $Q_{\rm EC}$ value. It means that the $Q_{\rm EC}$ window was covered completely. Furthermore, the intensity ratio for the observed most intense γ line over the observed weakest γ line reached to 5×10^3. In the decay scheme we found 13 1$^+$ states in low-lying region of the daughter nucleus ^{130}La. 13 1$^+$ states were also found in the low-lying region of ^{128}La via the EC/β$^+$ decay scheme of ^{128}Ce reported by our group in 1999[4]. The low-lying 1$^+$ states in La populated by EC/β$^+$ decay of Ce is shown in Fig. 3. The experimental data for A = 132 and 134 were reported by Abdurazakov[9] and Islamov[10], respectively. Using QPNM (quasi-particle-phonon nuclear model) and GTpp interaction, i. e. a RPA calculation

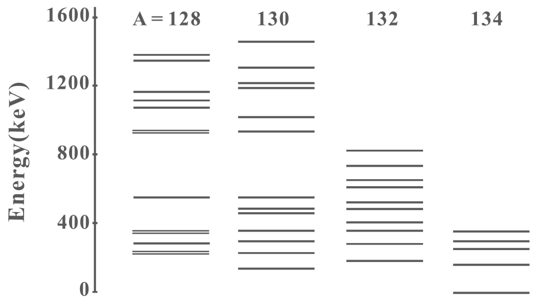

Fig. 3. Low-lying 1^+ states in La isotopes populated by EC/β^+ decay of even-even Ce isotopes with $A = 128$ to 134.

including separable p-p and p-h interaction, Kuzmin & Soloviev[11] could reproduce Gamow-Teller strength for the EC/β^+decay near the double magic nuclei, such as ^{100}Sn and ^{146}Gd. They made a similar calculation for the EC/β^+ decay of ^{130}Ce based on the spin-flip mode $\pi d_{5/2} \rightarrow \nu d_{3/2}$. The calculated log$ft$ value, 4.2, could be consistent with the experimental integrated logft value, i. e. the logft value integrated over the 13 1^+ states in ^{130}La. We don't know why the single particle configuration $(\pi d_{5/2}, \nu d_{2/3})1^+$ fragments, and then the Gamow-Teller transition is fed into 13 1^+ states. What interaction leads to the fragmentation?

2.4 Odd-odd nucleus

If the ground-state band in the daughter, even-even nucleus has been already known, the ground-state spin and parity for the mother, odd-odd nucleus can be determined by its EC/β+ decay. According to logft value, the allowed transitions are fed to 2^+, 4^+ and 3^+ states in ^{128}Ce in the proposed EC/β^+ decay scheme of ^{128}Pr[5]. Therefore the spin and parity of ^{128}Pr ground state was assigned to be 3^+, which is not consistent with the theoretical predictions 5^+ with the configuration $\nu7/2[523]\times\pi3/2[541]$, given by Möller et al based on their macroscopic-microscopic model[12]. However, the projected shell model calculation[5] could reproduce the experimental assignments 3+ with the configuration $\nu1/2[541]\times\pi5/2[532]$ and a large quadrupole deformation $\beta_2 = 0.408$. Is the large deformation reasonable?

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