Spectroscopy of ^{74}Ge : From soft to rigid triaxiality

J.J. Sun^a, Z. Shi^b, X.Q. Li^{a,*}, H. Hua^{a,*}, C. Xu^a, Q.B. Chen^a, S.Q. Zhang^a, C.Y. Song^b,
J. Meng^a, X.G. Wu^c, S.P. Hu^c, H.Q. Zhang^c, W.Y. Liang^a, F.R. Xu^a, Z.H. Li^a, G.S. Li^c,
C.Y. He^c, Y. Zheng^c, Y.L. Ye^a, D.X. Jiang^a, Y.Y. Cheng^a, C. He^a, R. Han^a, Z.H. Li^a, C.B. Li^c,
H.W. Li^c, J.L. Wang^c, J.J. Liu^c, Y.H. Wu^c, P.W. Luo^c, S.H. Yao^c, B.B. Yu^c, X.P. Cao^c,
H.B. Sun^d

^a School of Physics and State Key Laboratory of Nuclear Physics and Technology, Peking University, Beijing 100871, China

^b School of Physics and Nuclear Energy Engineering, Beihang University, Beijing 100191, China

^c China Institute of Atomic Energy, Beijing 102413, China

^d College of Physics Science and Technology, Shenzhen University, Shenzhen 518086, China

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ABSTRACT

The first heavy ion fusion–evaporation reaction study for ^{74}Ge has been performed through the reaction channel $^{70}\text{Zn}(^{7}\text{Li}, 2np)^{74}\text{Ge}$ at beam energies of 30 and 35 MeV. Previously known yrast band is extended to higher spins and five new collective bands are established. Based on comparison with the neighboring $^{72,76}\text{Ge}$ isotopes, an intermediate pattern of energy staggering $S(I)$ is observed in the γ band of ^{74}Ge . The collective structure of ^{74}Ge , including the excitation energies and transition probabilities of ground-state band and γ band, is reproduced by the state-of-the-art five-dimensional collective Hamiltonian (5DCH) model constructed from the covariant density functional. By including the $^{72,76,78}\text{Ge}$ isotopes, systematical investigation of the structure evolution in Ge isotopes is performed. Based on the systematic comparisons and analysis, the triaxial evolution with spin in ^{74}Ge is revealed and ^{74}Ge is found to be the crucial nucleus marking the triaxial evolution from soft to rigid in Ge isotopes.

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1. Introduction

Being an extremely complicated quantum finite many-body system, the spatial distribution of an atomic nucleus exhibits a variety of intriguing geometric shapes. The possible shapes which the nucleus adopts result from the competition and delicate balance of the collective vibrational, rotational, and single-particle degrees of freedom. Most nuclei have been found to have axially symmetric shapes. With the breaking of axial symmetry of the quadrupole deformation, some nuclei appear to have triaxial shapes. The triaxial degree of freedom of a nucleus has led to many interesting phenomena including the γ band [1], wobbling motion [1–3] as well as nuclear chirality [4–6], and continues to be a hot issue in nuclear structure physics.

One of nuclear regions with the triaxiality significantly involved is around neutron number $N \sim 40$. In particular, for the even–even Ge isotopes where a gradual shape transition around $N \sim 40$ has

been suggested experimentally [7–21], the low-lying second excited 2^+ states (γ band-head) indicating the importance of the triaxiality have been observed in $^{70,72,74,76}\text{Ge}$ isotopes [9–12]. The experimental analyses and theoretical calculations suggested that the low-lying structures of $^{70,72,74,76}\text{Ge}$ isotopes have large γ values ($\gamma \sim 30^\circ$) [9–11,16,22–25]. It should be mentioned that whether the triaxiality in these nuclei is soft or rigid has not been discussed in these previous studies. To address this question, the energy staggering $S(I)$ of adjacent levels within γ band [26,27] has been recently used to investigate the triaxial shape in ^{76}Ge [28]. For a γ -rigid rotor, the levels of γ band exhibit a $(2^+, 3^+)$, $(4^+, 5^+)$, $(6^+, 7^+)$, ... grouping, which is different from the γ -soft model pattern of 2^+ , $(3^+, 4^+)$, $(5^+, 6^+)$, ... grouping. Based on the analysis of $S(I)$ in the γ band, ^{76}Ge was proposed to be the lone instance of a nucleus with a rigid triaxial shape in this mass region, while the neighboring Se and Kr isotopes were suggested to have soft-triaxial shapes [28]. It is therefore very important to explore how the triaxiality evolves from γ softness to γ rigidity with spin and isospin in this mass region.

As a neighboring nucleus of ^{76}Ge , the spectroscopy of ^{74}Ge has been previously studied by many experiments [29]. Since few

* Corresponding author.

E-mail addresses: lixq2002@pku.edu.cn (X.Q. Li), hhu@pku.edu.cn (H. Hua).

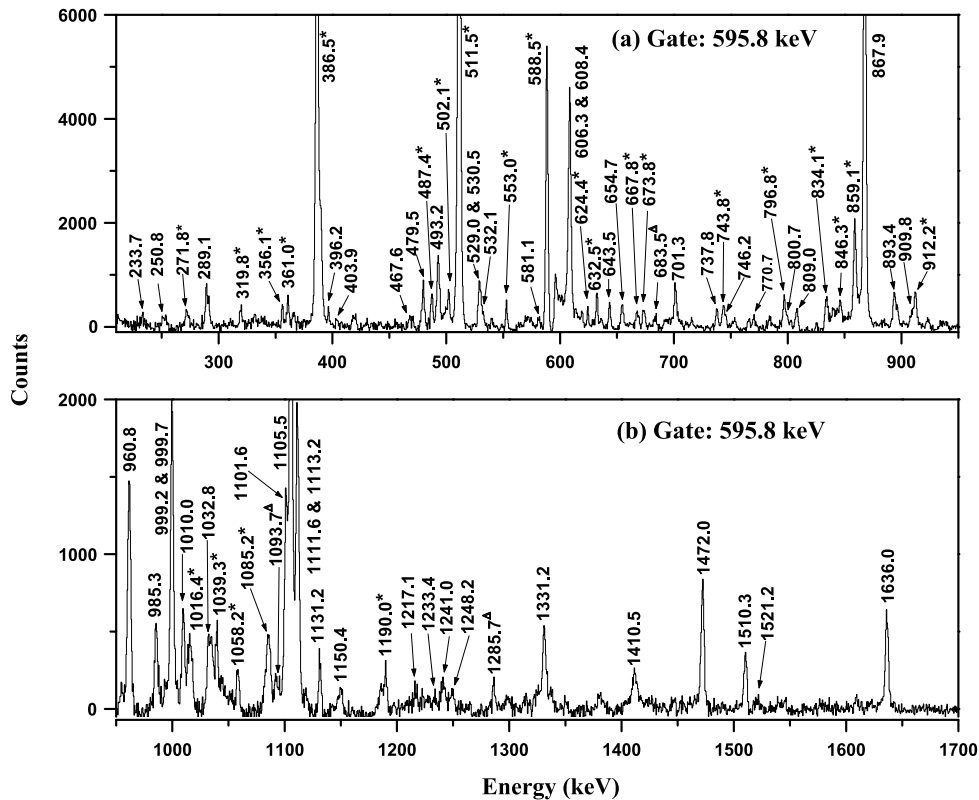


Fig. 1. Coincident γ -ray spectra with gating on 595.8 keV transition. The peaks marked with stars are known contaminants from other nuclei, and the peaks marked with triangles are the deexcited transitions from individual levels of ^{74}Ge which are not included in the partial level scheme of Fig. 3.

suitable stable target/heavy-ion beam combinations are available to populate ^{74}Ge via the fusion-evaporation reactions, the collective structure in ^{74}Ge has not been well developed. So far, only the yrast band of ^{74}Ge was established up to spin 8^+ at 3681 keV via $^{192}\text{Os}(^{82}\text{Se}, X\gamma)$ deep-inelastic reaction [30,31]. Thus, extending the spectroscopic study to ^{74}Ge would shed new light on the triaxial rigidity/softness and also the structure evolution in Ge isotopes.

In this letter, the first heavy ion fusion-evaporation reaction study for ^{74}Ge through the reaction channel $^{70}\text{Zn}(^7\text{Li}, 2n\text{p})^{74}\text{Ge}$ is reported. The collective structure of ^{74}Ge is expanded significantly and the structure evolution in Ge isotopes is investigated in terms of the state-of-the-art five-dimensional collective Hamiltonian (5DCH) based on the covariant density functional theory (CDFT).

2. Experiment and results

The present experiment was performed at the HI-13 tandem facility of the China Institute of Atomic Energy (CIAE). The high-spin states of ^{74}Ge were populated via the $^{70}\text{Zn}(^7\text{Li}, 2n\text{p})^{74}\text{Ge}$ fusion-evaporation reaction at the beam energies of 30 and 35 MeV. In the first run with 30 MeV beam energy, the target thickness was 2.15 mg/cm² with 0.93 mg/cm² Au backing. The deexcitation γ rays were detected by a γ detector array which consists of 12 high-purity germanium (HPGe) detectors with BGO anti-Compton suppressors and two planar HPGe detectors. In the second run with 35 MeV beam energy, the target thickness was 3.48 mg/cm² with 15.75 mg/cm² Pb backing. The γ detector array consists of 11 high-purity germanium (HPGe) detectors with BGO anti-Compton suppressors and two planar HPGe detectors. In both runs, the energy resolutions of these detectors were 2.0–3.0 keV at 1.33 MeV.

All detectors were calibrated using the standard ^{152}Eu and ^{133}Ba γ -ray sources.

A total of 2.0×10^8 coincident events were collected, from which a symmetric γ - γ matrix was built. The level scheme analysis was performed using the RADWARE program [32]. The typical γ -ray spectra gated on the 595.8 keV transition in ^{74}Ge are shown in Fig. 1. In order to obtain the Directional Correlations of γ rays deexciting Oriented states (DCO) intensity ratios to determine the multiplicities of γ -ray transitions, the detectors around 90.0° with respect to the beam direction were sorted against the detectors around 40.0° to produce a two-dimensional angular correlation matrix. To get clean DCO values for transitions in ^{74}Ge , gates were set on uncontaminated stretched $E2$ transitions. In general, stretched quadrupole transitions were adopted if DCO ratios were larger than 1.0, and stretched dipole transitions were assumed if DCO ratios were less than 0.8. The DCO ratio is plotted as a function of γ -ray energy for most of the observed transitions in ^{74}Ge in Fig. 2.

The partial level scheme of ^{74}Ge deduced from the present work is shown in Fig. 3. It was constructed from γ - γ coincident relationships, intensity balances, and DCO analyses. The only previous known yrast band (band 1) of ^{74}Ge is extended from spin 8^+ at 3680.8 keV to spin 12^+ at 5921.0 keV. By requiring the coincidence with the known γ -ray transitions under spin 6^+ of the yrast band in ^{74}Ge , seven new coincident γ -ray transitions of 530.5, 581.1, 800.7, 1331.2, 1410.5, 1521.2 and 1636.0 keV are observed in the γ -ray spectra. Based on the DCO ratio analyses and coincident relationships, band 2 is firstly constructed in the present work. In the neighboring isotopes $^{66,68}\text{Ge}$, the continuation of the ground-state band has been observed [33,34] and was found to become the non-yrast band around spin 6^+ . The similar γ -ray transition sequence and the spin at which band crossing occurs as $^{66,68}\text{Ge}$

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