Band structures in ^{99}Rh

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Introduction

Nuclei with neutron number in vicinity of the major shell closure at N = 50, and the proton number lying between the semi-closed Z = 40 and the closed Z = 50 shells provide particularly good laboratories to probe weakly deformed nuclei. The Rh (Z = 45) isotopes provide a platform for various intriguing phenomenon, where the proton Fermi surface lies in the middle of the $g_{9/2}$ proton shell (half-particle and half-hole). The low-j $\pi p_{1/2}$ orbital inundated in the opposite-parity high-j $\pi g_{9/2}$ orbitals is responsible for existence of isomeric states in the odd-A $_{45}$Rh isotopes due to the hindered high multipolairty γ-decay. The neutron valence space with reference to the N = 50 core consists of the $\nu d_{5/2}$, $\nu g_{7/2}$, and $\nu s_{1/2}$ orbitals. The prolate-driving low-Ω $\nu h_{11/2}$ intruder orbital starts filling up for Rh isotopes with neutron number above N $\approx$ 54 and exhibit configuration dependent triaxiality achieved due to interplay of the competing shape driving ability of the $\nu h_{11/2}$ and $\pi g_{9/2}$ orbitals. In case of the lighter isotopes, the $\nu h_{11/2}$ orbitals are accessible at $\sim$ few MeV excitation energy. The two and three quasiparticle bands in Rh isotopes [odd and odd-odd] involving the $\pi g_{9/2} \otimes \nu h_{11/2}$ and $\pi g_{9/2} \otimes \nu(h_{11/2})^2$ configurations show signatures of triaxial nuclear shape with large positive γ parameter. The other neutron and proton states coming from the normal-parity subshells do not drive deformation very much, except the intruder [431] $1/2^+$ proton orbital originating from the $\pi g_{7/2}$ subshells located above Z = 50 major shell gap. The deformation-producing tendency of the np interaction operating between valence particles in the spin-orbit partner (SOP) orbits, viz., the $\pi d_{5/2}$, $\nu d_{3/2}$, $\pi g_{9/2}$, and $\nu g_{7/2}$ orbits, is intricately responsible for the shape transition in this mass region [1, 2]. Large spatial overlap between the $\nu g_{7/2}$ and $\pi g_{9/2}$ SOP orbitals accentuates the importance of strong np interaction and three-quasiparticle configurations containing these orbitals are expected to compete with other three-quasiparticle configurations involving aligned $\nu h_{11/2}$ neutron pair [2]. Due to limited number of valence particles (holes) in the nuclei in the vicinity of ^{90}Zr, terminating states with the nuclear spin made up completely from angular momentum contributions of aligned quasiparticles of specific valence-space configurations and core-excited configurations, are likely to compete energetically with the deformed collective structures in the experimentally observable spin region. Such band terminating states have been recently observed in and $^{98-100}$Ru, $^{101-103}$Rh, ^{98,99,102,103}Pd, and ^{98,99}Ag nuclei.

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Experimental details

High angular momentum states in the ^{99}Rh nucleus were populated in fusion-evaporation reaction ^{75}As (^{28}Si, 2p2n) at E_{lab}=120 MeV. The ^{28}Si beam was delivered by the 15UD Pelletron accelerator at Inter University Accelerator Centre (IUAC), New Delhi. The ^{75}As target of thickness 3 mg/cm^2 onto a 10 mg/cm^2 thick Pb backing was prepared by vacuum evaporation followed by rolling. The recoiling nuclei are stopped within target and the de-excitations have been investigated through in-beam γ-ray spectroscopic techniques. The deexciting γ rays were detected using the Indian National Gamma Array (INGA) equipped with 18 clover detectors mounted in five rings configuration [4]. The photopeak efficiency of the array is ∼3% at the 1.3 MeV γ-ray energy. A total of about 300 million triple or higher-fold coincidence events were recorded in the experiment. The ^{103}Ag compound nucleus produced in the present reaction is found to decay via (i) 3-particle channels, viz., p2n (^{100}Pd), α2n (^{97}Rh), and 2αn (^{94}Tc) with relative population of ∼ 9%,6%, and 2%, respectively, (ii) 4-particle channels, viz., p3n (^{99}Pd), 2p2n (^{99}Rh), and αp2n (^{96}Ru) with relative population of ∼ 12%, 26%, and 20%, respectively, and (iii) 5-particle channels, viz., p4n (^{98}Pd), 2p3n (^{98}Rh), and αp3n (^{95}Ru) with relative population of ∼ 4%, 13%, and 2%, respectively. The clover detectors used in addback mode results in higher efficiency at γ-ray energies above ∼ 1 MeV. The energy and efficiency calibrations of the clover detectors were done using the ^{133}Ba and ^{152}Eu radioactive sources. In the offline analysis, the coincidence events were sorted using INGASORT program [3] to produce symmetrised E_γ-E_γ matrices and E_γ-E_γ-E_γ cubes with different conditions. The RADWARE program package was used to establish energy, intensity, and coincidence relationships for various observed γ-ray transitions, and perform the angular correlation and polarization analyses.

Results and Discussion

Excited states in the ^{99}Rh nucleus were populated using the reaction ^{75}As (^{28}Si, 2p2n) at E_{lab}=120 MeV, and the de-excitations were investigated through in-beam γ-ray spectroscopic techniques using INGA spectrometer consisting of 18 clover detectors. The level structures in ^{99}Rh have been established up to excitation energy ∼17 MeV and angular momentum ∼30$\hbar$. The deduced band structures are discussed in the framework of Spherical shell model and Cranked shell model calculations. Level structures at low energies are identified as resulting from the rotational bands based on the $\pi p_{1/2}$ and $\pi g_{9/2}$ configurations. The states of high-K $\pi g_{9/2} \otimes \nu g_{7/2} \otimes \nu d_{5/2}$ configuration competing the $\pi g_{9/2}$ yrast band are also identified. The $\Delta I = 1$ coupled positive and negative parity bands are observed at higher excitation energies and have been interpreted as based on the $\pi g_{9/2} \otimes \nu(h_{11/2})^2$ and $\pi g_{7/2} \otimes \nu h_{11/2} \otimes \nu g_{7/2}$ configurations, respectively. A high spin band extending to $I^\pi = (63/2^-)$ is identified as a five-quasiparticle configuration with moderate deformation involving $\nu(h_{11/2})^3$ quasiparticles. Energetically favored maximally aligned states with $I^\pi = 37/2^+, 41/2^-, 55/2^-$ and $57/2^-$ are identified to compete the rotational states and interpreted using Nilsson-Strutinsky cranking formalism as built up from angular momentum coupling of the $\pi g_{9/2}$ with $\nu g_{7/2}$, $\nu d_{5/2}$, and $\nu h_{11/2}$ outside the quasi-magic ^{90}Zr core.

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