Shell model calculations 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 the weakly deformed nuclei. Theoretical interpretations of level structures from new spectroscopic studies in these nuclei have revealed novel deformation-generating mechanisms[1, 2]. The Rh (Z = 45) isotopes with the proton Fermi surface in the middle of the $g_{9/2}$ proton shell (half-particle and half-hole), provide a platform for various intriguing phenomena. The occurance of 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[3–5] due to the hindered high multipole γ decay. The neutron valence space with reference to the N = 50 core consists of the $\nu d_{5/2}$, $\nu g_{7/2}$, $\nu d_{3/2}$, and $\nu s_{1/2}$ orbitals. The prolate-driving low-Ω $\nu h_{11/2}$ intruder orbital starts filling up in case of the Rh isotopes with neutron number above $N \approx 54$ and the configuration-dependent triaxiality is achieved due to the competing shape-driving ability of the $\nu h_{11/2}$ and $\pi g_{9/2}$ orbitals. The level scheme from the present work has been discussed within the framework of the spherical shell model [6].

Experimental details

High angular momentum states in the ^{99}Rh nucleus were populated in the 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 were stopped within target and the backing. The deexciting γ rays from the populated nuclei have been investigated through in-beam γ-ray spectroscopic techniques using the Indian National Gamma Array (INGA) [7] equipped with 18 clover detectors mounted in five rings configuration. The photopeak efficiency of the array is ∼5% at the 1.3 MeV γ-ray energy with all the 24 clover detectors in place in INGA. A total of about 300 million triple or higher-fold coincidence events were recorded in the experiment. The RADWARE software package [8] was used to establish the energy, intensity, and coincidence relationships for various observed γ-ray transitions, and perform the angular correlation and polarization analyses.

Spherical shell-model description

These calculations are also quite feasible for the ^{99}Rh nucleus as there are not too many active particles. The shell model provides a microscopic basis for the collective types of approach. In order to interpret the level structure of ^{99}Rh, state-of-the-art shell-model calculations have been performed using NuShell [9] computer code. The calculations have been carried out by taking $^{78}_{38}$Sr as core and $jj45pn$ model space involving valence protons distributed over the single particle $2p_{1/2}$ and $1g_{9/2}$ orbitals and neutrons

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occupying $1g_{7/2}$, $2d_{5/2}$, $2d_{3/2}$ and $3s_{1/2}$ orbitals with maximum four particles allowed in $d_{5/2}$ orbital. The $jj45pna$ effective interaction has been used in the calculations and the corresponding two-body matrix elements were obtained from the work of Hjorth-Jensen [10]. As the $h_{11/2}$ orbital is not included in the calculations, the positive-parity states in bands B1 and B2, and the negative-parity states in band B4 have been included for comparison with the predicted ones. The shell-model calculations reproduce the low-lying $7/2^+$, $11/2^+$, and $13/2^+$states very well with an energy difference of 25, 38 and 5 keV, respectively, whereas, the other calculated excitation energies for the levels with spin $I = 17/2^+$, $19/2^+$, $21/2^+$, $23/2^+$, $25/2^+$, $27/2^+$, $29/2^+$, and $31/2^+$ have reasonable good agreement with the experimental results. The calculations predict the $9/2^+$ state to be 85 keV above the $7/2^+$ state while it is observed 137 keV below the $7/2^+$ state. The lowest observed positive-parity state is $9/2^+$ and corresponds to wave function consisting of the $\pi(p^2_{1/2}g^5_{9/2}) \otimes \nu(g^2_{7/2}d^2_{5/2})$ configuration with an amplitude of 30%. The first excited $7/2^+$, $9/2^+$, $11/2^+$, $13/2^+$, $15/2^+$, $17/2^+$, $21/2^+$, $25/2^+$, and $29/2^+$ observed states are explained with $\pi(p^2_{1/2}g^5_{9/2}) \otimes \nu(g^2_{7/2}d^2_{5/2})$ configuration. The first excited $19/2^+$, $23/2^+$, $27/2^+$, and $31/2^+$, and the second excited $21/2^+$, $25/2^+$, and $29/2^+$ observed states are obtained by $\pi(p^2_{1/2}g^5_{9/2}) \otimes \nu(g^1_{7/2}d^3_{5/2}d^0_{3/2})$ configuration, i.e., excitation of $\nu g_{7/2}$ to $\nu d_{5/2}$. The details of the wave functions for the excited higher spins states of positive- and negative-parity states of ^{99}Rh corresponding to the experimental ones will be presented.

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