Excited States in doubly-Odd ^{98}Rh

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Introduction

Theoretical interpretation of the observed band structures in the doubly-odd nuclei is far more involving as compared to the odd-A or even-even neighbouring nuclei. It involves different types of coupling mechanisms of the odd-neutron and the odd-proton to the core, and the Coriolis response of the neutron and proton motion to the rotation of the core, proton-neutron ($\pi\nu$) residual interaction, and various novel deformation generating mechanisms for the even-even core. The coupling mechanism of an individual proton or neutron depends mainly on the deformation value of the core, the subshell angular momentum j, and its component Ω on the symmetry axis of the core. Investigations of excited states in the doubly-odd transitional nuclei, $Z < 50$ and $A \approx 100$, with weakly deformed even-even core ($\beta_2 \sim 0.1$) characterized by a γ-soft potential has been a fruitful theoretical construal over the years. The odd-odd Rh isotopes in this region contain five protons in the $p_{1/2}$, $f_{5/2}$, and $g_{9/2}$ shells and neutrons in the $d_{5/2}$, $g_{7/2}$, and $h_{11/2}$ shells outside the doubly quasi-magic ^{90}Zr (Z = 40) core. The spectra of low-lying yrast states of even-even $_{44}$Ru core isotopes are good examples of transitional systems between spherical vibrator and γ-soft nuclei . Triaxiality and γ-softness of nuclei is well-eveidenced by experimental observations and the phenomenological models. The prolate-driving low-Ω $\nu h_{11/2}$ intruder orbital starts filling up for the doubly-odd Rh isotopes with neutron number above N ≈ 55 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 . The bands built on the $\pi g_{9/2} \otimes \nu h_{11/2}$ configuration show signatures of triaxial nuclear shape with large positive γ parameter. For the lighter Rh isotopes, the $\nu h_{11/2}$ orbital is available at few MeV excitation energy, which increases with decreasing neutron number. The angular momenta of the valence protons, the valence neutrons and the core are mutually perpendicular [1]. The non-zero components of the total angular momentum on all the three axes can form chiral set. Spontaneous breaking of chirality, a dichotomic symmetry, leads to doublets of closely lying rotational bands of the same parity. Such bands have been reported for ^{102,104,106}Rh isotopes.

For nuclei near Z ~ N ~ 50 closed shells, the terminating states of the basic configuration obtained via coupling of the valence $\pi p_{1/2}$, $\pi f_{5/2}$ and $\pi g_{9/2}$, and $\nu d_{5/2}$, $\nu g_{7/2}$ and $\nu h_{11/2}$ quasiparticles will be in the medium spin region ~ 20 $\hbar$ and are likely to compete energetically with the deformed collective structures in the experimentally observable spin region. The terminating states based on the valence-space and core-excited configurations have been recently observed in $^{98-100}$Ru, $^{101-103}$Rh, ^{98,99,102,103}Pd, and ^{98,99}Ag nuclei, and configurations are interpreted using Nilsson-Strutinsky cranking formalism.

Experimental Details

Excited states in the ^{98}Rh nucleus were populated in the ^{75}As (^{28}Si, 2p3n) fusion-evaporation reaction using the 120 MeV ^{28}Si beam. The experiment was carried out at Inter University Accelerator Centre (IUAC), New Delhi. The ^{28}Si projectiles were provided by the 15UD Pelletron accelerator. The target ~ 3 mg/cm^2 thick (ΔE ~ 20 MeV) was prepared by vacuum evaporation of natural ^{75}As on to ~ 10 mg/cm^2 natural Pb backing followed by rolling. The ^{103}Ag compound nucleus produced in the present reaction is found to decay via several reaction channels associated with (i) 5-particle emission, viz., p4n (^{98}Pd), 2p3n (^{98}Rh), and αp3n

(^{95}Ru) with relative population of ~ 4%, 13%, and 2%, respectively, (ii) 4-particle emission, viz., p3n (^{99}Pd), 2p2n (^{99}Rh), and αp2n (^{96}Ru) with relative population of ~ 12%, 26%, and 20%, respectively, and (iii) 3-particle emission, viz., p2n (^{100}Pd), α2n (^{97}Rh), and 2αn (^{94}Tc) with relative population of ~ 9%, 6%, and 2%, respectively.

The recoiling nuclei are stopped within the target and the de-excitations have been investigated through in-beam γ-ray spectroscopic techniques. The γ decays of the excited states in ^{98}Rh have been investigated using an early implementation phase of the Indian National Gamma Array (INGA) which at that time comprised 18 large clover detectors mounted in five rings configuration **[2]**. The clover detectors were used to detect the deexciting γ rays in the coincidence mode. 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 clover detectors facilitate coincidence polarization measurements for the γ rays. These clover detectors used in addback mode also result in higher efficiency at γ-ray energies above ~ 1 MeV and are useful for studies involving high-energy γ rays which are likely to occur due to excitation of nucleons across the shell gaps. The energy and efficiency calibrations of the clover detectors were performed 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 in the Radford format and with different conditions of time window and multiplicity. The cubes were analyzed using the RADWARE analysis program package [4], which uses a generalized background subtraction procedure for extracting double-gated coincidence spectra from the cube. The selectivity afforded by ''double gating'' and the presence of many crossover transitions in the level schemes of ^{98}Rh provide many checks of the placement and ordering of transitions, and serve to augment confidence in the correctness of the proposed level scheme. The energy, intensity, and coincidence relationships for various observed γ-ray transitions are used to establish the ^{98}Rh level scheme.

Results and Discussion

Excited states in the previously studied ^{98}Rh nucleus [5] were populated using the fusion-evaporation reaction ^{75}As (^{28}Si, 2p3n) at E_{lab} = 120 MeV. The subsequent de-excitations were investigated through in-beam γ-ray spectroscopic techniques using Indian National Gamma Array (INGA) spectrometer consisting of 18 clover Ge detectors. The level structures in ^{98}Rh have been established up to excitation energy ≈ 10 MeV and angular momentum ≈ 23$\hbar$. Significant expansion of the level scheme at low excitation energies stipulates that the earlier reported 841-726-994-980-264 keV gamma-transition cascade in ^{98}Rh is not directly based on the ground state ($T_{1/2}$ = 8.7 m). Tilted-axis Cranking (TAC) shell model calculations have been used to put the level scheme of ^{98}Rh in perspective. Level structures have been interpreted in terms of the rotational bands based on the $\pi p_{1/2} \otimes \nu h_{11/2}$ [triaxiality parameter (γ) = 29°], $\pi g_{9/2} \otimes \nu g_{7/2}$ (γ = 9°), $\pi g_{9/2} \otimes \nu d_{5/2}$ (γ = 0°), and $\pi g_{9/2} \otimes \nu h_{11/2}$ (γ = 29°) proton-neutron configurations having moderate quadrupole deformation (ε_2) ≈ 0.10. High spin bands are identified as built on the fully stretched triaxial $[\pi p_{1/2} \otimes \nu d_{5/2} \otimes \nu(h_{11/2})^2]_{13-}$ (ε_2 = 0.17, γ = 37°) and the $\pi p_{1/2} \otimes \pi g_{9/2}{}^2 \otimes \nu h_{11/2}$ (ε_2 = 0.17, γ = 37°) configurations.

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