Exploring shell structure evolution above $N = 50$ by study of high-spin states in ^{89}Y

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Introduction

In recent years, investigation of high-spin states in nuclei near $N = 50$ shell closure have attracted considerable attention. These nuclei provide a suitable laboratory for testing the residual interactions of the spherical shell model. Study of $N = 50$, $Z \sim 40$ nuclei have revealed that the low-lying states in these nuclei arise from proton excitations within the $f_{5/2}$, $p_{3/2}$, $p_{1/2}$, and $g_{9/2}$ orbitals. The high angular momentum states were observed to have dominant contribution of $g_{9/2}$ neutron excitation across the $N = 50$ shell gap into the $d_{5/2}$ orbital A comprehensive study of multipaticle-multihole $(mp - mh)$ excitations in these nuclei may provide necessary insight into the evolution of shell structure above $N = 50$ shell gap.

However, these studies are challenging both experimentally and theoretically. The $N = 50$ shell gap is the largest near $Z \sim 40$ [1], making it difficult to populate such states in experiment. As a result, most of the available experimental information is limited to states involving $1p - 1h$ configurations involving a single $g_{9/2}$ neutron excitation across the $N = 50$ shell gap into the $d_{5/2}$ orbital, with little or no information on any other orbital above $N = 50$. The theoretical challenge lies in the exploding dimensions of the Hamiltonian matrices in large-scale shell model calculations incorporating cross-shell excitations, which resulted in huge truncation of the valence space in prior theoretical works

The present work reports on results of experiment performed at Tata Institute of Fundamental Research using the reaction ^{80}Se(^{13}C, p3n)^{89}Y, with the motivation to investigate the nature of states arising from cross shell excitations in the $N = 50$ nucleus ^{89}Y. The experimental observations have been explained by shell model calculations performed in a larger model space consisting of four active proton orbitals ($f_{5/2}$, $p_{3/2}$, $p_{1/2}$, $g_{9/2}$) and six active neutron orbitals ($p_{1/2}$, $g_{9/2}$, $g_{7/2}$, $d_{5/2}$, $d_{3/2}$, $s_{1/2}$) with respect to an inert ^{66}Ni core.

Experimental Details and Data Analysis

High-spin states in ^{89}Y were investigated using the heavy-ion fusion evaporation reaction ^{80}Se(^{13}C, p3n)^{89}Y. The 14UD TIFR-BARC Pelletron accelerator at Tata Institute of Fundamental Research provided the 60 MeV ^{13}C beam. The target consisted of a 500 μg/cm^2 thick layer of isotopically enriched ^{80}Se evaporated on an aluminium foil of 80 μg/cm^2 thickness. The target was mounted on a tantalum frame with the aluminum backing facing the incident beam. The γ-ray coincidence events were measured with the Indian National Gamma Array (INGA) spectrometer consisting of 18 Compton-suppressed clover detectors [2]. Two- and higher-fold clover coincidence events were collected in a fast digital data acquisition (DDAQ) system based on Pixie-16 modules of XIA LLC [3].

The γ-ray energies and efficiencies were calibrated with standard ^{152}Eu and ^{133}Ba radioactive sources. For the offline analysis, the coincidence events were sorted into γ^2 matri-

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ces and γ^3 cubes. The software package RADWARE [4] was used for the data analysis.

Results and Discussion

Prior to the present work, high-spin states in ^{89}Y have been investigated by means of a large variety of reaction and decay studies [5]. However, the spin and parity assignments of states above 6 MeV could not be confirmed. In addition, there are several contradictions between the level schemes obtained from different in-beam studies [5, 6]. In the present work, we have introduced several new levels and made more definite spin/parity assignment of most of the excited states on the basis of DCO and polarization measurements. A coincidence spectrum obtained by gating on the 470.5 keV transition is displayed in Fig. 1, where the newly identified transitions of ^{89}Y can be seen.

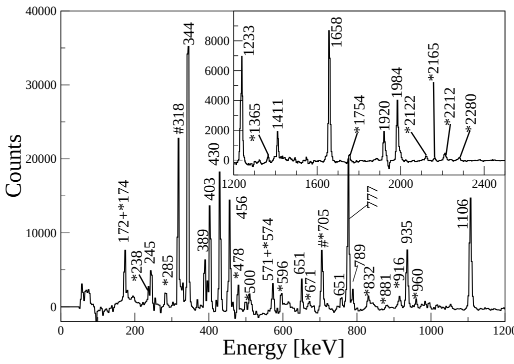

FIG. 1: Background corrected γ-ray coincidence spectrum showing transitions depopulating the states in ^{89}Y. The peaks marked with asterisks denote transitions newly identified in the present work. Hash marked peaks are unresolved doublets.

In order to understand the configuration of the observed states in ^{89}Y, shell model calculations were performed using the shell-model code NuShellX@MSU [7]. The calculations were carried out in the GWB model space with the residual interaction GWBXG. The valence space employed in the calculations consist of four proton orbits ($f_{5/2}$, $p_{3/2}$, $p_{1/2}$, $g_{9/2}$) and six neutron orbits ($p_{1/2}$, $g_{9/2}$, $g_{7/2}$, $d_{5/2}$, $d_{3/2}$, $s_{1/2}$) with an inert ^{66}Ni core. The single particle energies (in MeV) used were $\epsilon(\pi f_{5/2}) = -5.322$, $\epsilon(\pi p_{3/2}) = -6.144$, $\epsilon(\pi p_{1/2}) = -3.941$, $\epsilon(\pi g_{9/2}) = -1.250$, $\epsilon(\nu p_{1/2}) = -0.696$, $\epsilon(\nu g_{9/2}) = -2.597$, $\epsilon(\nu g_{7/2}) = 5.195$, $\epsilon(\nu d_{5/2}) = 1.830$, $\epsilon(\nu d_{3/2}) = 4.261$, and $\epsilon(\nu s_{1/2}) = 1.741$.

Due to computational difficulties, the calculations were performed by applying a truncation scheme, where only two $\nu g_{9/2}$ excitations across the $N = 50$ shell closure into any of the $g_{7/2}$, $d_{5/2}$, $d_{3/2}$, and $s_{1/2}$ orbitals were allowed. The valence protons were allowed to move freely among the $f_{5/2}$, $p_{3/2}$, $p_{1/2}$, $g_{9/2}$ orbits. Our preliminary calculations indicate that the states above $I^\pi = 17/2^+$ have significant contribution of $\nu g_{9/2}^{-1} d_{5/2}^1$ excitation, whereas, a dominant contribution of $\nu g_{9/2}^{-1}(d_{5/2}g_{7/2})^1$ configuration was observed above the $29/2^+$ state. Detailed shell model calculations are in progress.

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