Shell-model description of ^{90}Zr

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Introduction

Nuclei near closed shell are of special interest as they provide a platform for verification of shell-model (SM) theories. Excited states in these nuclei help in understanding the effective interactions and model space used in modern SM calculations. High spin structures in $A \sim 90$ region have been observed to develope $\Delta I = 1$ sequences with strong $M1$ transitions, where multiparticle-multihole configurations with $g_{9/2}$ orbital play a significant role. The effect of $\pi[1g_{9/2}]$ comes into picture due to excitation from fp orbitals across the $Z = 40$ subshell gap. These excitations dominate the lower energy part of the level scheme. However, it seems inadequate for the description of high spin states, where the role of $\nu[1g_{9/2}]$ orbital due to excitation across the $N = 50$ shell gap increases [1, 2]. The SM calculations have been successfully compared to describe observed excited states based on excitation either across $Z = 40$ or across $N = 50$ shell gap.

Experimental details and Results

Heavy-ion induced fusion-evaporation reactions ^{82}Se(^{13}C, 5n)^{90}Zr have been performed to populate excited states in ^{90}Zr. 60 MeV ^{13}C beam was provided by the TIFR-BARC PLF and 1 mg/cm^2 thick ^{82}Se target with Au-backing was used. γ-rays emitted were detected by INGA consisting of 11 clover HPGe detectors placed at 4 different angles w.r.t the beam direction. Two- and higher-fold coincidence events sorted into various $E_\gamma - E_\gamma$ matrices and $E_\gamma - E_\gamma - E_\gamma$ cube, and, have been analyzed using the RADWARE packages [3].

The placement of transitions have been confirmed through their coincidence relationships and intensity measurements (FIG. 1). For measuring spin and parity of states, we performed directional correlation of oriented states (DCO) and integrated polarization direction correlation of oriented states (IPDCO) methods, respectively. The spin assignment of positive parity states at 7222-, 7436-, 8056

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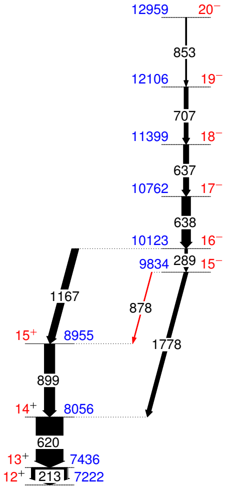

FIG. 1: Partial level scheme of ^{90}Zr. Newly observed transition and assignments are marked in red color. The energies are rounded off to nearest integers.

keV were tentative prior to this work. Above the 12^+ state at $E_x = 7222$ keV, the 213 and 620 keV transitions are determined as $M1$, which agree with the previously reported assignments up to 14^+ state [4]. However, the present results suggest the 899 keV transition to be of $M1$ type deduced from negative Δ_{asym}, thereby, differing from the result reported by Warburton *et al.*, where it is measured as $E1$-type. It is to be noted that this transition has contribution from ^{91}Zr too, and the limitation in the set-up used in Ref.[4] did not allow for clean measurements. This situation is remedied in the current measurements. This new identification in conjunction with 1167 keV transition of $E1$ type makes 10123 keV state as 16^-. In addition, by measuring R_{DCO} and Δ_{asym}, the 289-, 638-, 637-, 707-, and 853-keV transitions of the sequence are assigned as $M1$ type.

Shell-model calculations

To understand the structure of these states, SM calculations have been carried out with GWBXG effective interaction and ^{66}Ni core. The model space employed for the calculations includes $\pi[f_{5/2}, p_{3/2}, p_{1/2}, g_{9/2}]$ and $\nu[p_{1/2}, g_{9/2}, s_{1/2}, d_{5/2}]$ orbitals. Single particle energies used are $\varepsilon^{\pi}_{1f_{5/2}} = -5.322$, $\varepsilon^{\pi}_{2p_{3/2}} = -6.144$, $\varepsilon^{\pi}_{2p_{1/2}} = -3.941$, $\varepsilon^{\pi}_{1g_{9/2}} = -1.250$ MeV for proton orbitals, and $\varepsilon^{\nu}_{2p_{1/2}} = -0.696$, $\varepsilon^{\nu}_{1g_{9/2}} = -2.597$, $\varepsilon^{\nu}_{3s_{1/2}} = +1.741$, $\varepsilon^{\nu}_{2d_{5/2}} = +1.830$ MeV for neutron orbitals. At the most one neutron is allowed in $d_{5/2}$ orbital. Calculations are performed with the SM code KSHELL [5].

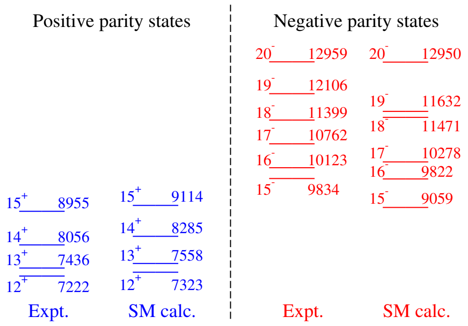

FIG. 2: Comparison of the experimental excitation energies and SM calculations both for positive and negative parity states.

Positive and negative parity states have $\pi[(2p^{-2}_{1/2})(1g^{2}_{9/2})] \otimes \nu[(1g^{-1}_{9/2})(2d^{1}_{5/2})]$, and $\pi[(1f^{-1}_{5/2})(2p^{-2}_{1/2})(1g^{3}_{9/2})] \otimes \nu[(1g^{-1}_{9/2})(2d^{1}_{5/2})]$ as the most dominant configurations, respectively. High spins are generated by the recoupling of the stretched proton and neutron configurations. States of both parities up to highest observed excitation energies and spins indicate the dominance of single-particle excitations in this nucleus.

Acknowledgments

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