Experimental investigation of particle-hole excitations in ^{91}Nb

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Introduction

Investigation of high-spin states in nuclei near $N = 50$ shell closure have attracted considerable attention in recent years. These nuclei provide a suitable laboratory for testing the residual interactions of the spherical shell model. Studies of $N = 50$, $Z \sim 40$ nuclei, 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 $g_{9/2}$ orbits. The higher angular momentum states were observed to have dominant contribution of $1p - 1h$ configurations involving a single $g_{9/2}$ neutron excitation across the $N = 50$ shell gap into the $d_{5/2}$ orbit [1]. 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, till date there is no experimental evidence of states involving two or more neutron excitations across the $N = 50$ shell gap in $N = 50$, $Z \sim 40$ nuclei.

The present work investigates high-spin states in the $N = 50$ nucleus, ^{91}Nb, with the purpose to search for states involving $2p - 2h$ excitations across the $N = 50$ shell closure.

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Experimental Details and Data Analysis

High-spin states in ^{91}Nb were investigated using the heavy-ion fusion evaporation reaction ^{65}Cu(^{30}Si, 2p2n)^{91}Nb. The 14UD TIFR-BARC Pelletron accelerator at Tata Institute of Fundamental Research provided the 137 MeV ^{30}Si beam. The target consisted of a 850 μg/cm^2 thick self-supporting foil of isotopically enriched ^{65}Cu. The γ-ray coincidence events were measured with the Indian National Gamma Array (INGA) spectrometer consisting of 21 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 matrices 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 ^{91}Nb were observed up to an excitation energy of 10 MeV and spin $35/2\hbar$ by Luo *et al.* [5], however parity of any of the observed states above $21/2\hbar$ could not be determined. In the present work, we have been able to firmly assign spin and parities to the levels, on the basis of DCO and polarization measurements. In addition, we have identified a new structure consisting of a cascade of dipole transitions, extending up to spin $43/2\hbar$ and excitation energy 12.5 MeV. The dipole cascade decays to the previously known positive parity states through several transitions in the energy range 1.5-2.0 MeV. A double gated coincidence spectrum is displayed in Fig. 1, where the newly identified transitions of ^{91}Nb can be seen.

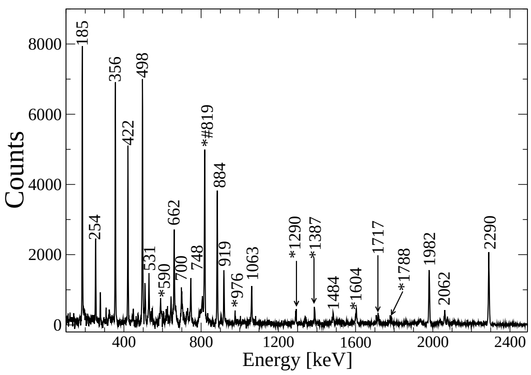

FIG. 1: Double gated γ-ray coincidence spectrum showing transitions depopulating the states in ^{91}Nb. The peaks marked with asterisks denote transitions newly identified in the present work. Hash marked peaks are unresolved doublets.

In order to understand the configuration of the observed states in ^{91}Nb, shell model calculations were performed using the shell-model code NuShellX@MSU [6]. 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 within a truncated model space, where a single $\nu g_{9/2}$ excitation across the $N = 50$ shell closure into the $\nu d_{5/2}$ orbit was allowed. This truncation scheme was adopted based on the observation that it has adequately described the observed level structure of other N=50 isotones [1]. The valence protons were allowed to move freely among the $f_{5/2}$, $p_{3/2}$, $p_{1/2}$, $g_{9/2}$ orbits. We observed that, at spin $I \geq 17\hbar$, the experimental excitation energies show large deviation (of the order of 1 MeV) from those predicted using shell model. The large discrepancy suggests that configurations limited to $1p{-}1h$ excitations are inadequate in explaining the observed level structure at high spin. Contribution of two or more neutron excitations across the $N = 50$ shell gap should also be included in the calculations. Detailed shell model calculations are in progress.

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References

[1] S. S. Ghugre and S. K. Datta, Phys.Rev. C **52**, 1881 (1995).
[2] R. Palit *et al.*, Nucl. Instrum. Methods A **680**, 90 (2012).
[3] H. Tan *et al.*, in 2008 IEEE Nuclear Science Symposium and Medical Imaging Conference (2008 NSS/MIC), Dresdan, 2008 (IEEE, New York, 2009), p. 2471
[4] D. C. Radford, Nucl. Instrum. Methods A **361**, 297(1995).
[5] P. W. Luo *et al.*, Phys. Rev. C **89**, 034318 (2014).
[6] B.A. Brown and W.D.M. Rae, Nuclear Data Sheets **120**, 115 (2014).