Microscopic investigation of nuclear structure of ^{89,91}Zr nuclei

Anuradha Gupta, Surbhi Gupta, Suram Singh and Arun Bharti
Deptartment of Physics and Electronics,
University of Jammu, Jammu – 180006, INDIA
** email: annu1gupta1@gmail.com*

Introduction

With the advent of first generation radioactive ion beam facilities as well as other new experimental techniques, the high spin nuclear structure of neutron rich nuclei near spherical shell nuclei can be obtained by aligning valence shell nucleon's angular momentum. The Zr nuclei lies in the transitional region having Z = 40 is of special interest as variety of nuclear structural effects associated with significant variation of shape and deformation were presented in these nuclei. The zirconium isotopes have been found to be a subject to rather extensive treatment on the basis of simple shell-model descriptions. Various experimental studies to investigate their nuclear structure are as:

^{89}Zr nucleus has been extensively studied using high-resolution experiment at incident proton energy of 25 MeV. Both positive- and negative-parity states of these nuclei have also been investigated within the large basis shell model and a comparison is made compared with the experimental findings in the same work. Warburton extracted the excitation functions, angular distributions, γ-γ coincidences, linear polarization measurements and lifetimes from both Doppler shift attenuation and recoil distance measurements. The extensive level structure of ^{89}Zr nuclei has been explored qualitatively and were found to be due to the fragmentation of the $lg_{9/2}$, $2p_{1/2}$, $2p_{3/2}$ and $lf_{5/2}$ neutron-hole strengths by isospin splitting and core-polarization effects. Investigation of ^{91}Zr by high resolution (d,p), (p,p′) and (p,d) reactions show that levels based on different core states having same spin and parity, mix strongly with the single-particle states and also with each other. A shell-model calculations have been performed for N = 51 (i.e., ^{91}Zr) nuclei with ^{88}Sr taken as inert core. The spectroscopic factors, E2 transition rates and two-body matrix elements were also calculated and compared with the experimental and theoretical results. These experimental as well as theoretical investigations have been mainly focused on investigation of high spin intruder bands and nuclear structure phenomena related to them along with the analysis of the band structure. In the present work, Projected Shell Model is applied to study the band structure of ^{89,91}Zr nuclei.

Outline of Theory - PSM

The PSM [1] is a truncated shell model scheme build over the deformed Nilsson + Single particle basis. Pairing correlations are incorporated into this basis from BCS calculations. The deformed Nilsson single particle basis which is defined in the intrinsic frame restores the broken rotational symmetry by standard angular momentum projection technique. Afterwards, the rotationally invariant Hamiltonian is diagonalized in the projected basis states. Thus PSM is formulated as the same basic philosophy of nuclear shell model approach. The states of odd proton nuclei in PSM are assumed to be constructed by two quasi-neutrons, one quasi-proton and a collective core. The core is assumed to be an assembly of even neutrons and even protons, which is coupled with the odd neutron and the odd proton through a quadrupole-quadrupole interaction.

The Hamiltonian used in the present study is

$$\hat{H}_{QP} = \mathrm{H_o} - \frac{1}{2}\chi\sum_{\mu} \hat{Q}^{\dagger}_{\mu}\hat{Q}_{\mu} - G_M \hat{P}^{\dagger}\hat{P} - G_Q\sum_{\mu}\hat{P}^{\dagger}_{\mu}\hat{P}_{\mu}$$

where H_o represents the spherical single particle shell model Hamiltonian, involving spin-orbit interactions while the second term includes the quadrupole-quadrupole interaction and third and fourth terms denote the monopole and quadrupole pairing interactions respectively. "χ" denotes the strength of these two body quadrupole interaction. In the present work, nuclear structure of ^{89,91}Zr nuclei has been analyzed with in a framework of Projected Shell Model. Various nuclear structure properties have been extracted and then the result of the present theoretical calculations has also been compared with the available experimental data. A small prescription of the results of the present work is described hereunder:

Results and Discussions

Analysis of band structure of ^{89,91}Zr nuclei has been made within two body effective quadrupole-quadrupole and quadrupole- as well as monopole- pairing inter actions. The description of band structures of odd mass $^{89\text{-}91}$Zr nuclei based on the band diagrams indicates the presence of multi-quasi-particle structure which provides us a unified understanding of ever accumulating high spin structure of these nuclei. In the present work, calculations describe the experimental data nicely, including the yrast spectra, back-bending in moment of inertia. From the calculations, it has been found that:

- The available experimental data [2,3] on lowest energy levels known as yrast line for ^{89,91}Zr nuclei is reproduced correctly by the PSM.
- Band structure of ^{89,91}Zr nuclei shows that low spins are generated by one-quasi-particle bands but multi-quasi-particle bands contribute the formation of high spin states which provides us a unified understanding of ever accumulating high spin structure of these nuclei.
- Since the low-lying states are found to arise from 1-*qp* states. But at higher angular momentum states, the intrinsic state changes and has 3-*qp* configurations. The theoretical results reproduce the observed first and second back-bending for the isotopes under study. PSM calculations provide an adequate descry ption of the available experimental data and thus validate the chosen valence space for these set of nuclei.

Summary

To summarize, it has been found that PSM results provide a good description of the quasi-particle structure of yrast states in ^{89,91}Zr nuclei. The calculated results are also compared with the available experimental data and a very good agreement has been found which successfully tests the validity of the chosen valence space. For the lower spins, yrast band is produced by 1-qp bands only whereas multi-quasi-particle configurations contribute to the formation of yrast band at higher spins.

References

[1] K. Hara and Y. Sun, Int. J. Mod. Phys. E **4,** 637 (1995).
[2] Balraj Singh, Nuclear Data Sheets **114**, 1 (2013).
[3] Coral M. Baglin, Nuclear Data Sheets **114**, 1293 (2013).