Evidence of rotational behavior in ^{86,88}Zr

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Introduction

The study of low- and high-spin phenomena in the proton-rich mass-80 nuclei has attracted considerable interest in recent years. This has been motivated by the increasing power of experimental facilities and improved theoretical descriptions, as well as by the astrophysical requirement in understanding the structure of these unstable nuclei. The study of superdeformed (SD) nuclei has been at the forefront of nuclear structure research during the last decade. SD structures in the A~80 region possess many surprising features. With the advent of large γ-ray detector arrays, new regions of SD nuclei have been uncovered encompassing mass A~80 [1] and A~60 [2]. Detailed studies of SD in these mass regions have been mainly due to the coupling of Gammasphere [3] with the Microball [4], a 4π charged-particle detector array. According to mean-field models, single-particle level densities in these mass regions are noticeably low. There are significant shell gaps at the prolate deformation $\beta_2 \approx 0.4$ with the particle number 38 or 40 and at oblate deformation $\beta_2 \approx -0.3$ with the particle number 34 or 36, which leads to rich shape transitions with changing nucleon numbers. In comparison to the rare-earth region where the change in nuclear structure properties is quite smooth with respect to particle number, the structure of the proton-rich mass-80 nuclei shows considerable variations when going from one nucleus to another. This is mainly due to the fact that the available shell model configuration space in the mass-80 region is much smaller than in the rare-earth region. Hence, with this motive in mind, the present work has been mainly focused on studying the interplay between the proton and neutron orbitals in evaluating the structure of ^{86,88}Zr nuclei.

In recent years, great effort has been made in identification and theoretical interpretation of rotational bands in Zr isotopes. Several investigations had been performed on the level structure of ^{86}Zr prior to this work and as a result, the Zr nuclei provide an excellent laboratory for studying the interaction between single-particle and collective degrees of freedom. In order to explain the highly deformed structure of some Zr nuclei, an attempt has been made in the present work to explain the structure of ^{86,88}Zr (Z = 40) nuclei in the PSM and the present PSM calculations have been found to explain most of the experimental observations quite successfully in these Zr nuclei.

The Theory of the Applied Model

To carry out the nuclear structure calculations for ^{86,88}Zr nuclei, Projected Shell Model [5, 6] is employed, which is the modified form of the shell model approach. However, unlike the conventional shell model, the PSM begins with the deformed (Nilsson-type) single particle basis. Such a shell model basis violates the rotational symmetry, but it can be restored by the standard angular-momentum projection technique. In this section, we are giving a brief introduction of the PSM. The total Hamiltonian is of the form

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

where, H_o represents the spherical single particle Shell Model Hamiltonian, 2nd, 3rd and 4th terms in the Hamiltonian denote the two-body interactions: quadrupole-quadrupole, monopole-pairing and quadrupole-pairing forces, respectively. χ denotes the Q.Q force strength and its value is adjusted via self-consistent conditions with a given quadrupole deformation ε_2. The choice of the strengths G_1 and G_2 depends on the size of the single particle gaps in the calculations. The quadrupole pairing strength, G_Q, is supposed to be proportional to G_M and is adjusted to be 0.22. For the present calculations, pairing strengths G_1 and G_2 are adjusted as 22.50 and 13.00 respectively. The other set of deformation parameters, quadrupole (ε_2) and hexadecapole (ε_4) are set as 0.240 and 0.060 and 0.200 and 0.000 for ^{86,88}Zr nuclei, respectively.

Results and Discussions

To extract structural information from the PSM calculations, it is useful to discuss the energies in terms of band diagram. Also, band diagram plays a crucial role for the interpretation of the yrast states, which is the lowest band and is obtained after configuration mixing of various multi quasi-particle configurations. In the present study, the yrast levels and their composition i.e., band structures from multi-quasi-particle configurations for ^{86,88}Zr nuclei have been investigated.

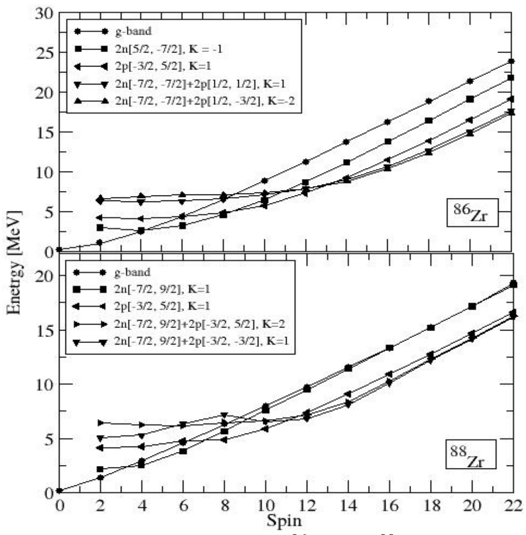

Fig. 1 Band diagrams of (a) ^{86}Zr, (b) ^{88}Zr

In the band diagram for ^{86}Zr, one can see at spin 4^+, 2-qp neutron band having configuration 2*n*[5/2, -7/2], K= -1, crosses the g-band and goes lower in energy. Again at spin 8^+, a 2-qp proton band having configuration 2*p*[-3/2, 5/2], K= 1crosses the above said 2*n* band and becomes lower in energy, thereby, contributing to the yrast formation. Further at spin 12^+, two 4-qp bands with configurations 2*n*[-7/2, -7/2]+2*p*[1/2, 1/2], K= 1 and 2n[-7/2, -7/2]+2*p*[1/2, -3/2], K= -2 cross the above cited bands which together goes lower in energy and contributes to yrast formation. In the band diagram for ^{88}Zr, upto the spin 4^+, the g-band is lowest in energy and contributes to the yrast formation. At 4^+, 2-qp neutron band having configuration 2*n*[-7/2, 9/2], K= 1, crosses the g-band and goes lower in energy. At spin 6^+, a 2 -qp proton band having configuration 2*p*[-3/2, 5/2], K= 1 crosses the above said 2*n* band and becomes yrast. Further, at spin 12^+ , two 4-qp bands with configurations 2*n*[-7/2, 9/2]+2*p*[-3/2, 5/2], K= 2 and 2*n*[-7/2, 9/2]+2*p*[-3/2, -3/2], K=1 crosses the above cited bands and then together goes lower in energy and contributes to yrast formation. Furthermore, Fig. 2(a-b) presents the yrast spectra of ^{86,88}Zr. The experimental data (taken from Refs.[7,8]) has been reproduced with an overall good agreement by the calculated values of energy for ^{86,88}Zr.

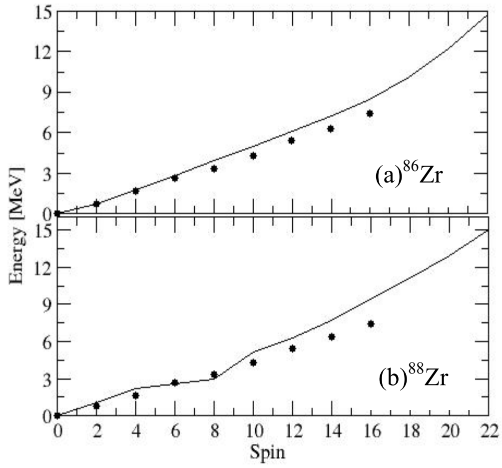

Fig. 2 Comparison of the Experimental and PSM yrast spectra for (a) ^{86}Zr, (b) ^{88}Zr

Summary

The neutron rich ^{86,88}Zr nuclei have been studied within a theoretical microscopic technique-Projected Shell Model. The composition of the yrast levels from various multi-quasi-particle configurations for ^{86,88}Zr isotopes has been well described. Further, the comparison of the yrast levels with the available experimental data has also been made and a good level of agreement has been obtained.

References

[1] C. Baktash, in Proceedings of the Conference on Nuclear Structure at the Limits, Argonne National Laboratory (ANL, 1997), p. 90.
[2] C. Svensson et al., Phys. Rev. Lett. **79**, 1223 (1997).
[3] Gammasphere Proposal, Report LBNL-PUB-5202; I.Y. Lee, Nucl. Phys. A **520**, 361 (1990).
[4] D.G. Sarantites et al., Nucl. Instrum. Methods Phys. Res. A **381**, 418 (1996).
[5] K. Hara and Y. Sun, Int. J. Mod. Phys. E **4,** 637 (1995).
[6] Y. Sun, Phys. Scr. **91**, 0403005 (2016).
[7] Alexandru Negret, Balraj Singh, Nucl. Data Sheets **124**, 1 (2015).
[8] E.A. Mccutchan and A.A. Sonzogni, Nucl. Data Sheets **115**, 135 (2014).