Microscopic Investigation of observed SD bands of ^{56}Ni

S. Pattnayak[1,*] C. Padhan[1], C.R. Praharaj[2], and Z. Naik[1]
[1]*School of Physics, Sambalpur University, Jyoti Vihar, Sambalpur – 768019, INDIA*
[2]*Institute of Physics, Sachivalaya Marg, Bhubaneswar-751 005, INDIA,*
* *email:* zashmir@suniv.ac.in, lisha.pattnayak010@gmail.com

Introduction

The study of rotational bands in the mass A≈60 region are of very interest due to the existence of highest rotational frequencies and the proximity to the N=Z line. A large number of high spin bands have been observed in the A=56-62 nuclei with N≥Z. However, the nucleus ^{56}Ni is of particular interest as its low lying and highly excited states reveals very interesting nuclear phenomena. According to the shell model description it is a doubly magic nuclei with N=Z=28 and is the smallest one generated by spin orbit coupling.

The experimental observation of ^{56}Ni gave different spherical levels including the ground state and two strongly deformed rotational bands in its low lying excited states [1]. Among the two rotational bands, the first band is explained with four particle-four hole excitations within the pf space and the second band is formed by the excitations of the nucleons in to the $1g_{9/2}$ orbital. Along with this a weak prompt proton decay to the ground state of ^{55}Co has been observed which has been recently established by E. K. Johansson *et al.* [2]. From the experimental observation, an evidence for shape coexistence in this nucleus has been found which was tried to explain within the large scale shell model by the quantum Monte Carlo diagonalization method by T. Mizusaki *et al*. [3]. The deformed trajectory canculated with CNS calculation in this article show that deformation decreases drastically with spin. Thus it is interesting to study this behavior with the help of microscopic calculation.

In the present work, we have theoretically investigated the rotational bands of ^{56}Ni and we have tried to explain the experimental observed spherical energy levels and strongly deformed bands with the microscopic Deformed Hartree-Fock (DHF) and Angular Momentum Projection model [4 , 5].

Formalism

A nucleons orbits $|\Omega\rangle$ for deformed shape is obtained by HF calculation and suitable nuclear intrinsic states $|\Phi_K\rangle$ are obtained by suitable occupations of nucleons to these orbits. These slater determinant $|\Phi_K\rangle$ of deformed orbits is localized in angle and, by the uncertainty principle, is not a state of good angular momentum (J). Thus $|\Phi_K\rangle$ does not have a unique J quantum number and is a superposition of various J states [2, 3, 6]

$$|\Phi_K\rangle = \sum_I C_{IK}\,|\Psi_{IK}\rangle \quad (1)$$

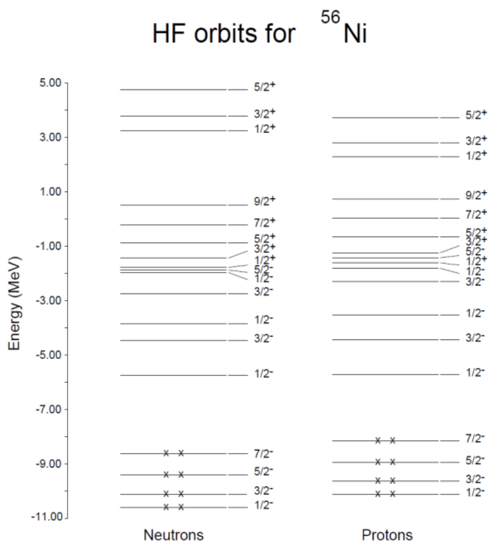

Fig.1 The ND prolate HF orbits of ^{56}Ni with β = 0.06. The parity and Ω are mention in the figure. Occupied orbits are denoted by (x).

The states of good angular momenta are obtained from the intrinsic state Φ_K with the help of angular momentum Projection Operator,

$$P_K^{\Im} = \frac{2I+K}{8\pi^2}\int d\Omega\, D_{MK}^{I}{}^{*}(\Omega)R(\Omega) \qquad (2)$$

In general two states $\left|\Psi_{K_1}^{JM}\right\rangle$ and $\left|\Psi_{K_2}^{JM}\right\rangle$ projected from two intrinsic configurations are not orthogonal to each other even if $\left|\Phi_{K_1}\right\rangle$ and $\left|\Phi_{K_2}\right\rangle$ are orthogonal. Thus whenever necessary the band mixing is done using the following equation

$$\sum_{K'}\left(H_{KK'}^{J} - E_J N_{KK'}^{J}\right)C_{K'}^{J} = 0 \qquad (3)$$

The deformed HF orbits are calculated with a spherical core of ^{40}Ca with four active neutrons and four active protons above the core. The model space spans the proton orbits $1p_{1/2}$, $1p_{3/2}$, $0f_{5/2}$, $1d_{5/2}$, $0f_{7/2}$, $0g_{9/2}$ having energies 2.353, 0, 2.770, 7.775, -4.081, 4.616 MeV and neutron orbits $1p_{1/2}$, $1p_{3/2}$, $0f_{5/2}$, $1d_{5/2}$, $0f_{7/2}$, $0g_{9/2}$ having energies 2.323, 0, 2.306, 8.794, -4.559, 4.381 MeV respectively. We use the surface-δ interaction among the active nucleons with nucleon-nucleon interaction strength $V_{pp} = V_{nn} = V_{np}$= 0.42MeV. Here we have considered 2p-2h and 1p-1h excitation for explaining the spherical energy level with ground state.

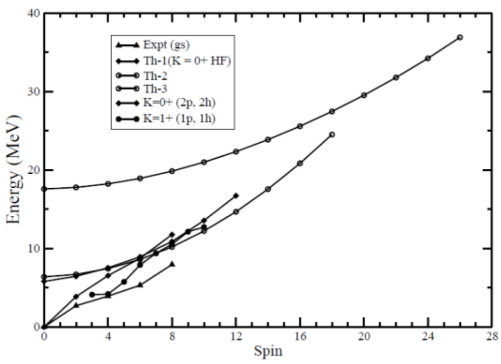

Fig.2 Comparison of theoretical ND and experimental yrast band and theoretical WD and SD band

Result and Discussion

To study the band structure of ^{56}Ni, we perform the HF calculation for both constrain and without constrain procedure. We obtained a HF solution at β = 0.06. The energy of the orbits is shown in Fig.1. To explain normal deformed (ND), well-deformed (WD) and superdeformed (SD) band, we consider the solution with β = 0.06, 0.38 and 0.59 respectively.

Before proceeding to study WD and SD bands we have tried to explain experimentally observed normal deformed band. We have considered different 2p-2h and 1p-1h excitation for normal deformed case and compared the spectrum with the yrast band which is shown in fig. 2. The excited energy of band with 2p-2h excitation is slight higher than the experimental yrast band at low spin. Thus we considered 1p-1h excitation for these non-collective states. Besides these we get the excitation energy of WD and SD bands to be 6.38 MeV and 17.59 MeV respectively. The detailed calculations on these bands are going on.

We have also considered the HF solutions with β = -0.16, -0.29 and -0.35 for J projection to investigate shape co-existence.

Conclusion

We have tried to explain the different high spin structures in ^{56}Ni and predicted collective and non-collective structure for future experiment. The prediction of shape co-existence is address in our calculation to give a microscopic explanation. J projection for prolate and oblate higher deformations are performed to get band structure of WD and SD nature.

References

[1] D. Rudolph *et al.*, Phys. Rev. Lett.**82**, 3763 (1999).

[2]E. K. Johansson *et al.*, Phys. Rev. **C77**, 064316 (2008).

[3] T. Mizusaki *et al.*, Phys. Rev. **C59**, R1846 (1999).

[4] G. Ripka, Advances in Nuclear Physics, Edited by M. Baranger and E. Vogt Plenum, New York, 1968) Vol. I page 183.

[5] Zashmir Naik, C. R. Praharaj, Phys. Rev. **C67**, 054318 (2003).

[6] R. E. Peierls and Y. Yoccoz, Proc. Phys. Soc. A70 381 (1957).