Role of Intruder Orbits in the structure of doubly shell closed ^{56}Ni

S. Pattnayak[1,3,*] C. Padhan[1], C.R. Praharaj[2], and Z. Naik[1]
[1]School of Physics, Sambalpur University, JyotiVihar, Sambalpur – 768019, INDIA
[2]Institute of Physics, SachivalayaMarg, Bhubaneswar-751 005, INDIA,
[3]G. M. Junior College, Sambalpur – 768004, INDIA.
* email:zashmir@suniv.ac.in, lisha.pattnayak010@gmail.com

Introduction

As per the shell model description ^{56}Ni is a doubly magic nuclei with N = Z = 28 and is the first shell closure generated after spin orbit coupling. The low lying spherical structure and possibility of excited deformed bands of this nucleus reveals many interesting nuclear phenomena in this mass region. Also the evidences for shape coexistence [1] and the experimentally observed strongly deformed collective bands [2,3] makes this nucleus an interesting topic for study its intrinsic structures microscopically.

The two rotational bands observed in the nuclei are explained with large scale shell model calculations, and are explain as extended sequence of spherical states [1]. Also it has been suggested that the superdeformed bands are due to large moment of inertia. Presence of limited numbers of particles (or holes) in $0f_{7/2}$ makes challenge to study of superdeformation structure in this nucleus. Thus it is important to study the influence of intruder orbits in highly deformed structure of ^{56}Ni nucleus.

In this work, we have theoretically studied the intrinsic structure of ^{56}Ni by deformed Hartree-Fock (HF) model [4, 5] and tried to explain the role of intruder orbit in ^{56}Ni structures at various deformations. This is a quantum mechanical approach, where all the matrix element are calculated by considering basic principle of shell model.

Formalism

To study the intrinsic structures of ^{56}Ni, we have performed free as well as constrained Deformed HF (DHF) calculation. Here the constraint applied in the iteration process is Quadrupole moment (Q_{20}). This constraint guides the HF solution to converge at different deformations and gives set of corresponding deformed single particle orbits. The Hamiltonian with the constraint is given as

$$H' = H + \lambda_2 Q_{20}$$

A nucleons orbits Ω (i.e. $|\alpha m\rangle$) for axial symmetry deformed shape (which is assumed in our calculation) can be written as

$$|\alpha m\rangle = \sum_j C_j^{\alpha m} |jm\rangle.$$

This mixing of orbital is due to two-body residual interaction. We have only considered mixing among same parity orbits.

The deformed HF orbits Ω are calculated with a spherical core of ^{40}Ca with eight active neutrons and eight 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 spherical single particle 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 surface-δ interaction among the active nucleons with nucleon-nucleon interaction strength $V_{pp}= V_{nn}= V_{np}= 0.45$MeV.

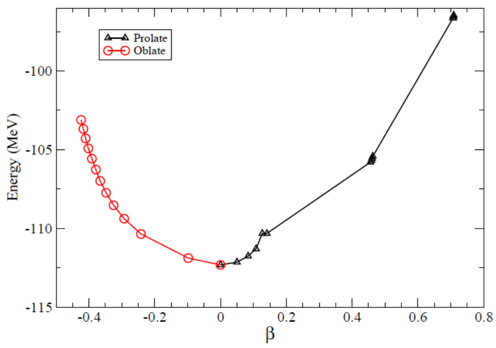

Fig: 1 β ~ HF Energy obtained with constraint calculation.

Result and Discussion

The HF calculation for both free as well as with constraint quadrupole is carried out. The plot of HF energy with the corresponding β is shown in Fig - 1. The free calculation results in spherical solution. The constrained calculation results, three prolate solutions with β=0.13 (Normal deformed or ND), β=0.45 (Superdeformed or SD) and β=0.71

(Hyperdeformed or HD).On the other hand in oblate we have several solutions with smoothly increasing in deformation. On oblate site two solutions with β= -0.098 (ND) and β=-0.4 (SD) have been considered for the study of intrinsic structures of ^{56}Ni as these two solutions having nearly the same energy correspond to ND and SD prolate solution. The HF solutions with corresponding HF energy, β and particle-hole configuration are given in Table – 1.

Table 1: HF energy, β and particle-hole configuration of various HF Solutions

HF Solution	β	HF Energy	Font type
Sph. solution	0.0	-112.32	$\pi(f_{7/2}^{8})\otimes\nu(f_{7/2}^{8})$
ND (Prolate)	0.13	-110.81	$\pi(f_{7/2}^{8})\otimes\nu(f_{7/2}^{8})$
SD (Prolate)	0.45	-105.79	$\pi(f_{7/2}^{-2}\otimes f_{5/2}^{2}\otimes g_{9/2}^{0})\otimes \nu(f_{7/2}^{-2}\otimes f_{5/2}^{2}\otimes g_{9/2}^{0})$
HD (Prolate)	0.71	-96.64	$\pi(f_{7/2}^{-4}\otimes f_{5/2}^{2}\otimes g_{9/2}^{2})\otimes \nu(f_{7/2}^{-4}\otimes f_{5/2}^{2}\otimes g_{9/2}^{2})$
ND (Oblate)	-0.098	-111.88	$\pi(f_{7/2}^{8})\otimes\nu(f_{7/2}^{8})$
SD (Oblate)	-0.4	-105.57	$\pi(f_{7/2}^{-2}\otimes p_{3/2}^{2}\otimes g_{9/2}^{0})\otimes\nu(f_{7/2}^{-2}\otimes p_{3/2}^{2}\otimes g_{9/2}^{0})$

For, β=0.45 the $0f_{5/2}$ orbit has been occupied by creating two holes each in $0f_{7/2}$ proton and $0f_{7/2}$ neutron orbits and near β=0.71, the $0g_{9/2}$ orbit has been occupied along with $0f_{5/2}$ by creating four holes both in $0f_{7/2}$ proton and $0f_{7/2}$ neutron orbit. The energy different between β=0.13 and β=0.45 is 5 MeV and between β= 0.45 and β=0.71 is 9.15MeV. In oblate side solutions are observed in regular interval giving a smooth variation in energy with deformation. The different solution is due to different particle-hole configuration in both prolate side (see Table. 1).

From the calculation we can see that in oblate side we are only getting the ND and SD solution. We have considered upto very high constrain value, but not getting the HD solution. To understand this we have plot β vs HF orbit energies. We get interesting results by investigate the plot. The plot is different from Nilsson orbit diagrams; particularly in oblate side and it explain very things. From the figure also we see that the role of $0g_{9/2}$ is more important to get the very deformed shapes.

As we have several HF solutions at different deformation, there are possibilities of shape coexistence at high angular momentum state. Such thing already been experimentally observed [6, 7, 8] this makes the study of the nucleus more interesting.

Conclusion

We have tried to explain the intrinsic structure of ^{56}Ni by applying constrained HF calculation and tried to explain various deformed shapes exist in the doubly magic ^{56}Ni nuclei. We obtained several deformed HF solutions both in prolate and oblate side. These solutions are useful to study the energy spectra from low to very high momentum inertia. The study shows that the intruder orbits ($1g_{9/2}$) play important role for creation of super-deformed and hyper-deformed shapes of this nucleus.

References

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

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

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

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

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

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

[7] S. Pattnayak, C. Padhan, C.R. Praharaj, and Z. Naik *Proceedings of the DAE Symp. on Nucl. Phys.* **59** (2014).

[8] S. Pattnayak, C. Pradhan, Z. Naik and C. R. Praharaj, Submitted to *Sambalpur University Journal of Science and Technology*.