Investigation of High Spin Bands of N or Z = 28 Nuclei by DHF Model

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Introduction

The proximity to the N=Z line and the presence of magic number of nucleons makes some of the nuclei in the A≈60 mass region more interesting for the study of high spin rotational bands. The experimental observation of many rotational bands in this mass region leads to the study of many nuclear high spin phenomena and to investigate the structure of nuclei. As the high spin states in this region involves the excitation of the nucleons to the very much shape driving orbital $0g_{9/2}$, this produces a number of well and superdeformed bands.

In the present work we have investigated the rotational bands of some of the nuclei having N or Z = 28 and the influence of the intruder $0g_{9/2}$ orbital in their structures. The doubly magic nucleus ^{56}Ni has attracted much attention as the possibility of different low lying states and excited deformed bands reveals many interesting nuclear phenomena. Along with ^{56}Ni, different rotational bands with high excitation energy have also been reported in the neighboring isotope of this i.e. in ^{58}Ni nucleus [1, 2]. Also an isomeric state has been reported in the ^{54}Ni nucleus [3]. This is why it is interesting to study the structure of these nuclei along with their neighboring nucleus by a microscopic approach. For this we have adopted the microscopic deformed Hartree-Fock(DHF) and Angular Momentum Projection model [4 , 5].

Formalism

The intrinsic structures of the different nuclei have been studied by performing 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;

$$H' = H + \lambda_2 Q_{20} \qquad (1)$$

A nucleons orbits $|\Omega\rangle$ for deformed shape is obtained by HF calculation and the nuclear intrinsic states $|\Phi_K\rangle$ are obtained by suitable occupations of nucleons to these orbits. The 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 the intrinsic states are obtained by superposition of various J states and the high spin states are obtained from the intrinsic states $|\Phi_K\rangle$ with the help of angular momentum Projection Operator [4, 5, 6];

$$|\Phi_K\rangle = \sum_I C_{IK} |\Psi_{IK}\rangle \qquad (2)$$

$$P^I_K = \frac{2I+K}{8\pi^2} \int d\Omega D^{I}_{MK}{}^{*}(\Omega) R(\Omega) \qquad (3)$$

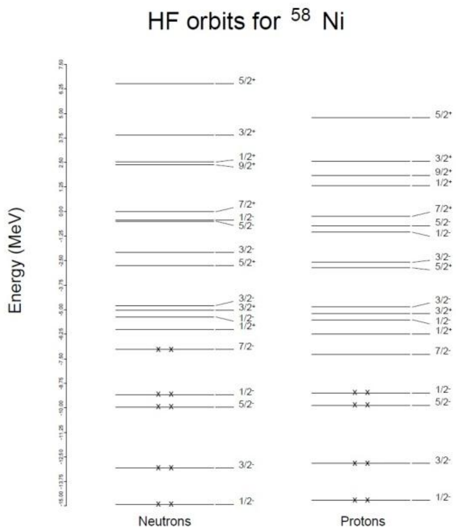

Fig.1 The SD prolate HF orbits of ^{58}Ni with β = 0.38. The parity and Ω are mention in the figure. Occupied orbits are denoted by (x).

The deformed HF orbits are calculated with a spherical core of ^{40}Ca with ten 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 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 $V_{pp} = V_{nn} = V_{np} = 0.42$MeV.

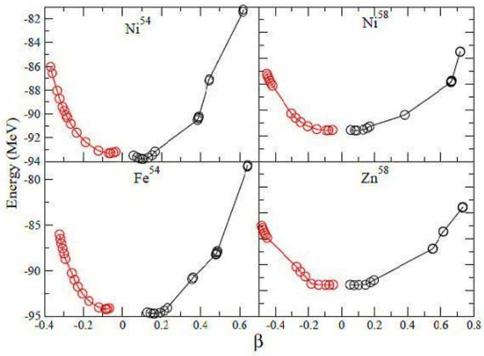

Fig.2 β ~ HF Energy obtained with constraint calculation.

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 for different nuclei i.e. ^{54}Ni, ^{58}Ni, ^{54}Fe and ^{58}Zn is shown in Fig – 2. In all the cases we get a solutions with smooth variation of increasing energy in oblate side and converged solutions in prolate side. However in higher deformation the prolate solutions are more favorable. Thus we have explained the high spin bands with prolate deformed solutions. In all the four cases, we get four solutions in prolate side.

Although we have calculated bands for all the four cases but in this paper we mainly concentrate on the deformed bands of ^{58}Ni. For the explanation of different low-lying, dipole dominated and quadrupole dominated structure, we have considered the prolate solution with β=0.17 and β=0.38. Besides these, two more solutions are obtained with β=0.66, and β=0.71 which are used to describe the higher deformation bands. The comparison of one of the quadrupole dominated structure Q_1 with the appropriate theoretical band is shown in Fig – 3. For this we have considered the prolate solution with β = 0.38. The energy of the theoretical bands is slightly lower than the experimental value but the slope of the bands are matching. For explaining the Q_1 band we have considered two configurations. The $K=0^+$ band has configuration as $\pi(f_{7/2}^{-2}\otimes f_{5/2}^{2}) \otimes \nu(f_{7/2}^{-2}\otimes f_{5/2}^{2}\otimes g_{9/2}^{2})$ and the $K=5^+$ band has the configuration $\pi(f_{7/2}^{-3}\otimes f_{5/2}^{2}\otimes g_{9/2}^{1}) \otimes \nu(f_{7/2}^{-1}\otimes f_{5/2}^{2}\otimes g_{9/2}^{1})$. For easy of comparison we have shifted the energy value around 1.5 MeV for the bands.

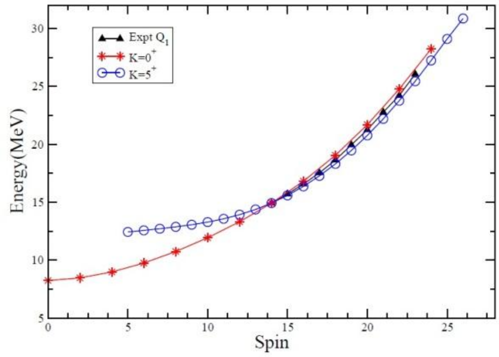

Fig.3 Comparison of theoretical bands with experimental Q_1 band [2].

Along with these the B(E2) and B(M1) values for all the bands are calculated. Also the values of Q_s, Q_0, β and μ for band heads are predicted for future reference.

Conclusion

We have tried to explain theoretically the different high spin rotational bands of nuclei with N or Z=28 by using the microscopic DHF and AMP Models. Considering the influence of the intruder $0g_{9/2}$ orbital, different superdeformed and higher deformed bands has been established in these nuclei. We have also calculated the microscopic properties of these bands for future reference.

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