Investigation of nuclear structure of Cu nuclei

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Introduction

With the advent of various recent developments in radioactive ion-beam facilities along with advanced nuclear detectors, it has been now possible to investigate the nuclear structure properties as well as the influence of the sub-shell closure on the behaviour of single-particle and collective properties of the nuclei lying in the neighbourhood of the magic nuclei. One such prominent case is the breakdown of the semi-magic number in the neighborhood of doubly magic Ni nucleus at $N = 40$. However, various emerging physics phenomena occurs in these neighbouring nuclei such as: a rapid decrease in stabilization effect takes place at sub-shell closure due to the significant polarization of ^{68}Ni core nucleus when coupled with valence nucleons [1]; the unexpectedly large value of $B(E2)$ is observed at low-excitation energies in ^{70}Ni [2] and ^{72}Cu [3] as well as the low value of energy of first excitation state, 2^+, state in ^{66}Fe [4] and the newly found isomeric state, $1/2^-$, in ^{67}Co [5], which have clearly revealed the weakening of the $N = 40$ shell closure when nucleons are added/subtracted from the Ni core. Thus, this region offers an interesting laboratory for their study and understanding new facets of nuclear structure. Since rich variety of nuclear structure phenomena is exhibited by the nuclei lying in the neighborhood of Ni nucleus, thus, it is a quite interesting to study these nuclei with the single particle deformed Nilsson potential.

To couple the extra proton with the excitations of the underlying core can be considered as a subject of particular interest. The best candidates chosen for the present study that lies in the neighborhood of Ni, are odd-proton ^{71,72}Cu nuclei. The aim of present paper is to analyze their high spin structure of the yrast band and its composition in terms of the contribution of multi-quasi-particle states. The phenomena of back-bending in moment of inertia and reduced transition probabilities of ^{71,72}Cu nuclei are also studied within a quantum mechanical framework – Projected Shell Model (PSM).

Theory of PSM

The description of heavy and deformed quantum mechanical nuclear systems needs modification of the fundamental shell model potential. One such modification of the shell model is known as projected shell model, which has been developed as a shell model truncation scheme to a deformed single particle basis and explains various available experimental features in a much simplest way to describe many-nucleon systems fully quantum mechanically. The detailed description of applied framework PSM can be found in review article [6]. Projected shell model basically starts with the deformed Nilsson single-particle states at some deformation, ε_2. Pairing correlations are incorporated into the Nilsson states by BCS calculations. Angular-momentum projection technique is carried to restore the broken symmetry in deformed Nilsson single particle basis. Finally, a two-body shell model Hamiltonian is diagonalized in the projected basis, thereby, obtaining the energy levels for a given spin. 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 $\mathrm{H_o}$ 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. The strength of these two body quadrupole interaction is described by the parameter "χ" which is adjusted to obtain quadrupole deformation, ε_2. In the present PSM calculations, we have used three major shells 1, 2, 3 (2,3,4) for protons (neutrons). The shell model space is truncated at energy window of 4.40 MeV and G_Q is taken as 0.16 times G_M for the present set of calculations.

Results and Discussions

The yrast energy levels, band structure, the back-bending in moment of inertia and reduced transition probabilities have been studied for the ^{71,72}Cu nuclei. Further, these results are also compared with the available experimental counterparts. In this abstract, only data corresponding to yrast band, band diagrams and back-bending in moment of inertia for ^{71}Cu has been displayed in Figs. 1, 2 and 3. Moreover, the complete picture of the results will be presented and discussed during the symposium.

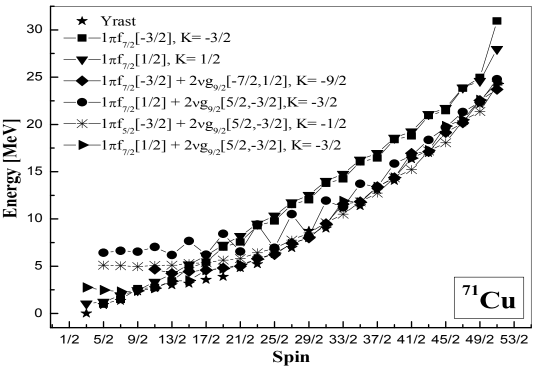

Fig. 1 Quasi particle structure of yrast band for ^{71}Cu.

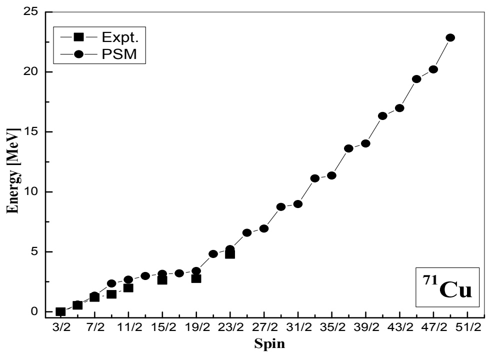

Fig. 2 Yrast energy states of the ^{71}Cu isotope.

From Fig. 1, it has been seen that for low spins upto $9/2^-$, yrast band is mainly comprised of two 1-qp bands having $K=1/2^-$ and $3/2^-$. Afterwards, a 3-qp band identified as, K = -3/2, crosses the 1-qp bands thereby making its contribution towards the formation of yrast band. At spin $17/2^-$, one more 3-qp band with K = -9/2 dives down in the yrast regions and thus forms the yrast band upto $25/2^-$. Beyond this spin value, two more 3-qp bands identified as, K= -3/2 and$1/2^-$ form the yrast along with the previously mentioned 3-qp bands upto the last calculated spin value. Furthermore, on comparing PSM results for the yrast levels (see Fig. 2) with the experimentally available data [7], a good agreement has been found. The moment of inertia has also been calculated and compared with the experimentally available data in Fig. 3. It has been found that experimental back-bending in moment of inertia at $9/2^-$ has been well reproduced by the present PSM calculations.

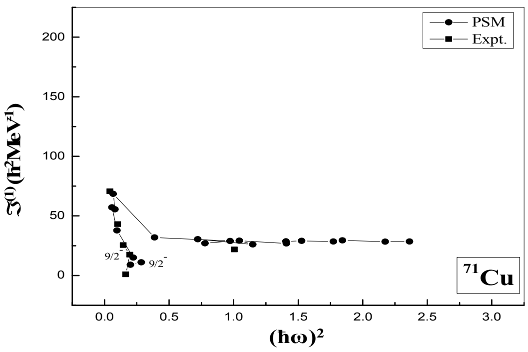

Fig. 1 Back-bending in moment of inertia in ^{71}Cu nuclei.

Summary

To summarize, it has been found that PSM results provide a good description of the quasi-particle structure of yrast states in ^{71,72}Cu nuclei. The calculated results are compared with the 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.

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