Negative parity band structure in odd-odd ^{60}Cu

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Introduction

The negative parity states in odd-odd nuclei in A ~ 60 mass region are generated when the odd-proton occupies the *fp* orbitals and odd-neutron occupies the $g_{9/2}$ orbital. The $g_{9/2}$ orbital is known to be a shape-driving orbital and therefore, such negative parity configuration is expected to be associated with deformed rotational bands. The energy systematics of the 6^- states (E_{6-}) in Cu and 8^- states (E_{8-}) in Co isotopes, corresponding to the $\pi(fp) \otimes \nu g_{9/2}$ configuration are shown in Fig.1. Similar behavior i.e decrease of energy as neutron number increases, is observed in both the cases. In ^{58}Cu, no 6^- state is known but a rotational band based on a state with unknown spin-parity (J^π) has been identified at high excitation [1]. In ^{62}Cu, rotational band based on the 6^- state has been reported [2]. Although 8^- states are identified in Co isotopes, but no rotational band is known. The earlier works on ^{60}Cu identified a 6^- state [3] which was later extended [4] but could not be interpreted as rotational band as a few transitions were missing. In this work, we tried to identify a rotational band in ^{60}Cu based on the 6^- state, which would provide a measure of the extent to which $g_{9/2}$ induces deformation in nuclei in this region.

Experiment and Analysis

The excited states in ^{60}Cu were populated by the *pn* evaporation channel following the fusion of 37-MeV α beam (from K-130 cyclotron at VECC, Kolkata) on a ^{58}Ni (99.48% enriched, 18 mg/cm^2 thick) target foil.

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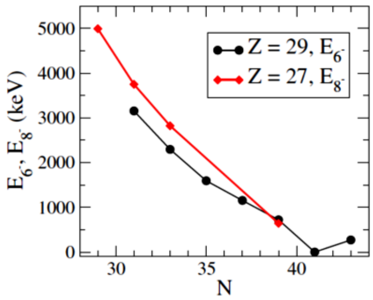

Fig.1: Energy of the 6^- (E_{6-}) & 8^- (E_{8-}) states of the $\pi(fp) \otimes \nu g_{9/2}$ configuration in Cu and Co nuclei.

The INGA setup, with 11 HPGe clovers (2 at 40^o, 6 at 90^o, 3 at 125^o) and a LEPS (at 40^o), was used for collecting two or higher fold γ–γ coincidence data using a PIXIE-16 based digital data acquisition system [5].

Results and Discussion

For data sorting and analysis, the codes BiNDAS [6], INGASORT [7] and Radware [8] were used. In order to study the excited states in ^{60}Cu, a γ–γ symmetric matrix has been made to check for coincidence relation to construct the level scheme, while two asymmetric coincidence matrices were made to determine the Directional Correlation from Oriented states ratio (R_{DCO}) and the polarization asymmetry ratio (Δ_{PDCO}) for J^π assignment. A total projection spectrum from symmetric matrix is shown in Fig. 2(a) in which, the known lines of ^{60}Cu are labelled, it shows the adequate production of ^{60}Cu. In addition to the known lines of ^{60}Cu reported in Ref. [3] and [4], we have also observed a few new gamma lines which are placed in the negative parity band. As an example, Fig.2(b) shows a spectrum gated by

1552 keV γ ray. All the γ lines, including the newly observed ones are seen in this spectrum.

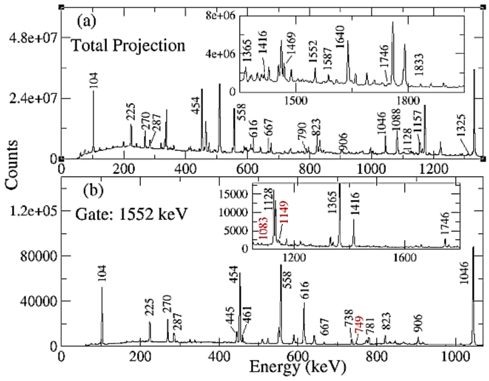

Fig.2: (a) Total projection spectra with ^{60}Cu lines labelled and (b) 1552-keV gated spectra with newly observed lines are shown in red colour.

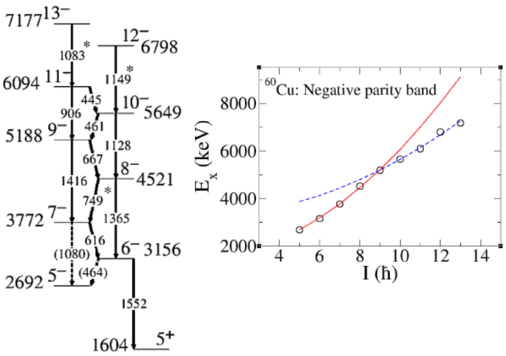

Fig.3: (Left) Partial level scheme of ^{60}Cu, showing the negative parity band, identified in this work. The new γ-lines are marked by ∗. (Right) Excitation energy (E_x) vs. spin (I) plot for the band (symbol) are fitted by rotational formula in the two spin regions (solid and dashed lines).

Fig.3 shows the partial level scheme (negative parity band) of ^{60}Cu in the left panel. With the placement of the newly observed γ lines in this band (marked by ∗), the rotational band-like structure with two signature partners has been established for the first time in this nucleus. The rotational model formula of excitation energy (E_x) vs. spin (I), i.e $E_x = A_0 + A_1 * I * (I+1)$, nicely fits the experimental points as shown in the right hand side of Fig.3. The lower and higher parts of the band fits two different parabolas, indicating a crossing of two bands at I ~ 9ħ. Similar negative parity band with 6^- band head has been recently reported in ^{62}Cu [2] but no band crossing was observed. The $\pi(f_{7/2}p_{3/2}) \otimes \nu g_{9/2}$ configuration is assigned for the lower part of the band in ^{60}Cu similar to that in ^{62}Cu. There seems to be a low-spin signature inversion in this band for ^{60}Cu, which suggests the possibility of triaxial shape for ^{60}Cu. This band decays to the 5^+ state by an E1 transition. A few other new E1 transitions have also been identified in this work. These indicate the presence of octupole correlation in ^{60}Cu.

Total Routhian Surface (TRS) calculations are performed for the negative parity configuration of ^{60}Cu. It predicts a γ-soft shape with minimum of the TRS at $\beta_2 = 0.27$ and $\gamma \sim +30^o$. At higher rotational frequency, the coexistence of prolate and triaxial shapes are predicted by the TRS.

Summary and Acknowledgement

A new negative parity rotational band, the first evidence of collectivity, has been established in ^{60}Cu. The reaction ^{58}Ni(^{4}He, pn)^{60}Cu at 37 MeV was used to populate the states and INGA was used to detect the prompt γ-rays. The states of the band nicely fit the rotational model formula with a band crossing at ~ 9ħ. This band is suggested to have $\pi(f_{7/2}p_{3/2}) \otimes \nu g_{9/2}$ configuration. TRS calculations predict γ-soft non-axial shape. Further analysis is in progress and the details will be presented.

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