Deformed nuclear shapes around N, Z = 28 in A = 50 - 60 region

S. Basu[1,2*], G. Mukherjee[1,2], S. Nandi[1,2], S. S. Nayak[1], S. Bhattacharyya[1,2], Soumik Bhattacharya[1], Shabir Dar[1,2], Sneha Das[1,2], S. Basak[1,2], D. Kumar[1,2], D. Paul[1,2], K. Banerjee[1,2], Pratap Roy[1,2], S. Manna[1,2], Samir Kundu[1,2], T. K. Rana[1,2], T. Bhattacharjee[1,2], R. Pandey[1], S. Samanta[3], S. Chatterjee[3], R. Raut[3], S. S. Ghugre[3], H. Pai[4], A. Karmakar[4], S. Chattopadhyay[4], S. Das Gupta[5], P. Pallav[5], R. Banik[6], S. Rajbanshi[7], S. Ali[8], Q.B. Chen[9], C. Bhattacharya[1,2]

[1]*Variable Energy Cyclotron Centre, 1/AF Bidhannagar, Kolkata- 700064, India*
[2] *HBNI, Training School Complex, Anushaktinagar, Mumbai-400094, India*
[3]*UGC-DAE CSR, Kolkata Centre, LB-8, LB Block, Sector III, Bidhannagar Kolkata 700098, India*
[4]*Saha Institute of Nuclear Physics, 1/AF Bidhannagar, Kolkata 700064, India*
[5]*Victoria Institution (College), Kolkata-700009, India*
[6]*Institute of Engineering and Management, Kolkata-700091, India*
[7]*Department of Physics, Presidency University, Kolkata-700073, India*
[8]*Government General Degree College at Pedong, Kalimpong, India*
[9]*East China Normal University, Shanghai 200241, China*
**s.basu@vecc.gov.in*

Introduction

The odd-A and odd-odd nuclei with proton (neutron) number below (above) Z = 28 shell closure, in the A = 50 ï 60 mass region, are experimentally studied by γ-ray spectroscopy method. The N = Z = 28 shell closure is the first (lowest) one originated specifically due to the effect of ℓ.s coupling and the doubly magic nucleus ^{56}Ni is considered as a softer core [1]. The high-j $1f_{7/2}$ and $1g_{9/2}$ neutron orbitals, lying below and above this shell closure, have shape driving effects leading to deformed collectivity. Consequently, in the neighboring isobar ^{56}Fe, in which the proton Fermi level lies below Z = 28 and neutron one above it, evidence of prolate-oblate shape coexistence are reported [2]. On the other hand, the introduction of GXPF1 effective interaction [3] predicts new subshell gaps at N = 32, 34 for the neutron rich nuclei in this region. The unique-parity $\nu g_{9/2}$ orbital also observed to play significant role for the higher spin states in the nuclei in this region [4]. Another important aspect is the possible presence of octupole correlation due to the $1g_{9/2}$ and $2p_{3/2}$ orbitals. These make it very interesting to study the excited states in nuclei in this region. For such study, we have a program for experimental investigation of odd-A and odd-odd nuclei (^{57}Fe, ^{54,55}Mn) around N, Z = 28. The observation of rotational bands indicated onset of deformation in ^{55}Mn and ^{57}Fe but, in contradiction to the previous study [5], no band structure has been observed in ^{54}Mn [6]. The detailed results on the odd-N ^{57}Fe are being presented here.

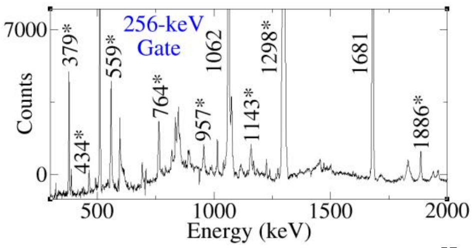

Fig. 1 γ-ray spectrum gated by 256 keV of ^{57}Fe. The newly observed transitions are marked by *.

Experiment

The excited states in the nuclei of interest were produced using ^{4}He + ^{55}Mn fusion evaporation reaction. The 34-MeV α beam was delivered from K-130 cyclotron at VECC. The target (MnO_2) thickness was 6 mg/cm^2 and was backed by 0.5 mg/cm^2 Mylar. The prompt γ rays from de-excited nuclei were detected using an array of 11 CS clover and 1 LEPS detectors placed at 3 different angles (125°, 90° and 40°). The data acquisition system was based on PIXIE-16 digitizer and processed by IUCIPIX package developed by UGC-DAE-CSR, Kolkata [7]. Further data analysis was done by using RADWARE software.

Analysis and Results

The energy calibrations of all the crystals of all the runs were done using known in-beam γ-lines and ^{152}Eu source. To analyze coincidence relation, DCO ratio and polarization, several symmetric and asymmetric γ–γ matrices were constructed. Fig. 1 shows a representative gated spectrum for ^{57}Fe.

Discussion

The known positive parity rotational band [8] in ^{57}Fe, based on $\nu g_{9/2}$ orbital, has been extended beyond band crossing. Several new γ-rays have been observed in the negative parity sequence, built on $\nu p_{3/2}/f_{5/2}$ orbitals, and it has been extended up to ~ 6.3 MeV. Earlier these states were interpreted as single-particle excitations. However, in the present work the non-yrast sequence (B1′) is found to form a rotational-like band, which decays to the yrast sequence (B1), more like a γ-band.

The band diagrams are well reproduced by particle-rotor model (PRM) calculations [9] as shown in Fig. 2, except for the yrast ï ve parity states which may be originated from single-particle excitations. The deformation parameters, (β_2, γ), used in the PRM calculations are (0.29, 0^o) and (0.23, 7.5^o) for +ve and ï ve parity bands, respectively. These are determined from the covariant density functional theory (DFT).

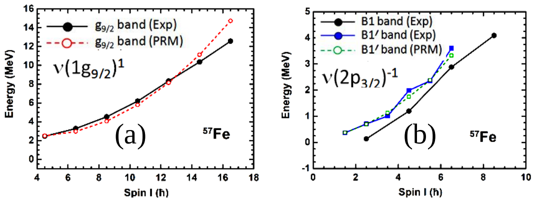

Fig. 2 Expt. and calculated (PRM) band diagrams of (a) +ve and (b) -ve parity sequences.

The Total Routhian Surface (TRS) calculations are also performed in ^{57}Fe and are shown in Fig. 3. It shows minima at β_2 = 0.28, γ = 5^o and β_2 = 0.18, γ = 19^o for the +ve and -ve parity configurations, respectively. The deformation parameters match well with DFT for +ve parity but differ for the ï ve parity configuration. The triaxiality for the ï ve parity band supports the possible occurrence of γ-band for the ï ve parity configuration in ^{57}Fe.

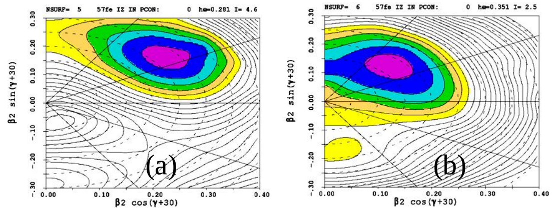

Fig. 3 TRS plots for the +ve (a) and the ï ve (b) parity configurations in ^{57}Fe.

Several ΔJ = 0 and ΔJ = 1, E1 transitions are also observed from the first few states of the $g_{9/2}$ band to the negative parity, $p_{3/2}$, states in ^{57}Fe. This indicates the presence of octupole correlation in ^{57}Fe due to $g_{9/2}$ and $p_{3/2}$ single particle orbitals.

Conclusion

The odd-A and odd-odd nuclei in mass region A = 50 ï 60 have been experimentally investigated using α-induced fusion evaporation reaction. The results of ^{57}Fe nucleus show rotational bands build on both positive ($g_{9/2}$) and negative ($f_{5/2}$ / $p_{3/2}$) parity configurations. The experimental data are well reproduced by PRM calculations. Both DFT and TRS calculations predict deformed shape for both configurations. Several observed E1 transitions indicate octupole correlation in ^{57}Fe.

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References

1. K. Arnswald, et al., Phys. Lett. B **820** 136592 (2021).
2. D.E. Appelbe et al., Phys. Rev. C **62,** 064314 (2000).
3. M. Honma, et al., Phys. Rev. **C 65**, 061301(R) (2002).
4. A. Deacon et al., Phys. Rev. C **76**, 054303 (2007).
5. G Kiran Kumar et.al., J. Phys. G: Nucl. Part. Phys. 35, 095104 (2008).
6. S. Basu et al., Proc. DAE-NP Symp. Vol. **64**, 66 (2019).
7. S. Das et al., Nucl Inst Meth Phys Res. **A893**, 138 (2018).
8. P. Banerjee et al., Nuovo Cim. **85A,** 54 (1985).
9. S. Frauendorf and F. Dönau, Phys. Rev. C 89, 014322 (2014).