Systematic analysis of low to high-spin structures in N = 33, 35, 37 Zn isotopes on the basis of fp and $f_{5/2}pg_{9/2}$ shell model calculations

Anirban Goswami, Shubharthi Maiti, Sramana Biswas,
Koustav Bhandary, A. Chakraborty, and B. Mukherjee*
Department of Physics, Siksha-Bhavana, Visva-Bharati,
Santiniketan, West Bengal 731235, INDIA

Introduction

Many experimental as well as theoretical attempts have been undertaken for studying the properties of A $\approx$ 60-70 isotopes of Ge, Ga, Zn, Cu, and Ni. ^{60,61,65,66}Zn are some of the nuclei exhibiting high-spin excitation phenomena like superdeformation, rotational deformation, band crossing, and band termination [1-6]. The main explanation for the origin of these highly deformed structures is the excitation of one or more nucleons from the $1f_{7/2}$ orbitals to the intruder $1g_{9/2}$ orbitals via the N = Z = 28 shell gaps. Consequently, it appears that the A $\approx$ 60-70 mass regions provide a suitable platform for testing the predictivity of various nuclear models.

Considering the $f_{5/2}pg_{9/2}$ limited model space, where the active nucleons are permitted to distribute among the $1f_{5/2}$, $2p_{3/2}$, $2p_{1/2}$, and $1g_{9/2}$ orbitals, S. Rai et al. [7] performed a shell model study for the even-even Zn isotopes with N = 30, 32, 34, 36 using the effective Hamiltonians, JUN45 [8] and jj44b [9]. Limited shell model anticipated findings persist for the ^{63,65,67}Zn isotope triplet.

Results and Discussion

Since the excitation energies, B(E2) values and level lifetimes that were obtained from their calculations utilizing the (1.80e, 0.65e) set of proton and neutron effective charges agreed well with the observed outcomes corresponding to a majority of states, we have chosen the same set for the JUN45 interaction in the $f_{5/2}pg_{9/2}$ model space and the GXPF1A [10] interaction in the full fp model space with ^{40}Ca inert core (in order to elucidate the importance of the $1f_{7/2}$ orbitals) to perform large-scale shell model calculations for even-odd ^{63,65,67}Zn nuclei using NuShellX@MSU code [11] for the states up to $31/2_2^-$ and $41/2_2^+$. We have restricted the minimum number of particles in the $1f_{7/2}$ (π and ν) orbitals of these neclei to 6, 5 and 4, respectively. In the present manuscript, however, we are presenting partial level schemes concerning the negative parity states (see Fig. 1). In the symposium, the remaining level schemes and all the reproduced lifetimes, B(E2) and B(M1) values, magnetic and spectroscopic quadrupole moments will also be presented. Regarding the ground state spin-parity of either of ^{63}Zn and ^{65}Zn, the JUN45 Hamiltonian concurs with observation while GXPF1A can reproduce the correct ground state spin-parity for ^{63}Zn only. However, the predictions for ^{67}Zn from both the interactions are incorrect. The observed and GXPF1A calculated B(E2) values regarding a few yrast negative parity states are presented in Fig. 2. An excellently significant contribution of the shape-driving $\nu(1g_{9/2})$ orbital is found in forming the wave functions for almost all of the higher-lying negative parity states in ^{67}Zn. Regarding every isotope, the lower value of the rms

TABLE I: rms deviation $\sqrt{\frac{\sum_i (E_i - C_i)^2}{N}}$ of the calculated (C_i) energies from the observed (E_i) ones.

^{63}Zn				^{65}Zn		^{67}Zn	
G	J	G*	J*	G	J	G	J
229	363	67	73	162	253	7	148

---

*Electronic address: `buddhadev.mukherjee@visva-bharati.ac.in`

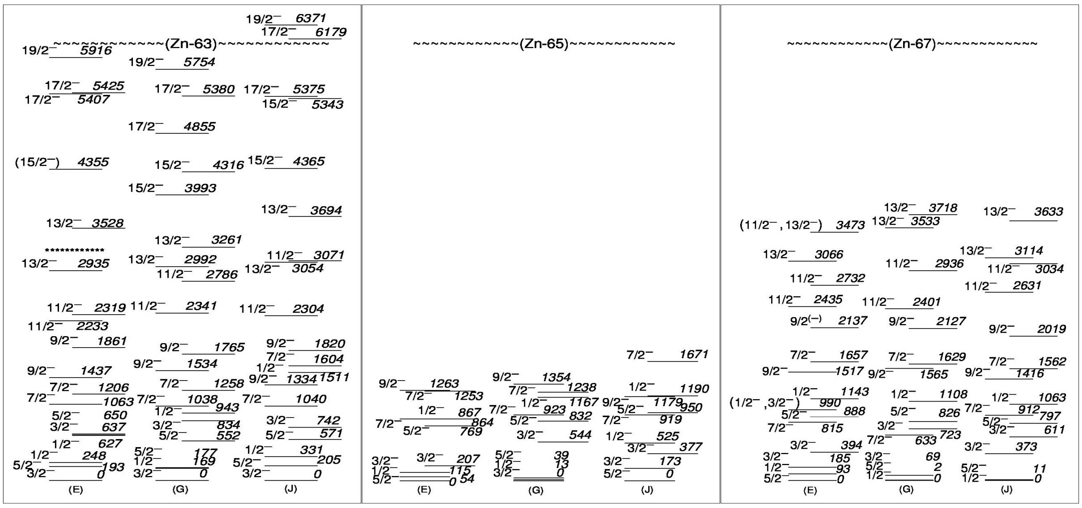

FIG. 1: Energy-systematic and Comparison of the GXPF1A (G) and JUN45 (J) calculated negative parity states' excitation energies with the observed analogs (E) [12] for ^{63,65,67}Zn. The energies are in keV.

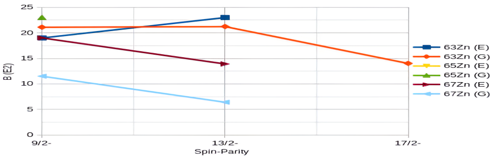

FIG. 2: Variation in observed and GXPF1A predicted B(E2, I→I-2) (W.u) with spin (I).

energy deviation of the fp calculated state energies than that of the $f_{5/2}pg_{9/2}$ calculated ones mean that the fp model space suits better, and therefore, in developing the low-spin states, the $1f_{7/2}$ orbital contributes more than the $1g_{9/2}$ orbital (see Table I). The rms deviation drops rapidly with increase in the number of neutrons. If one considers only the yrast states with energies up to 2935 keV, substantially lower rms deviations (67 keV and 73 keV) are obtained for ^{63}Zn. For ^{67}Zn, the fp predicted and the observed state energies accord exceptionally well.

Acknowledgments

The help received from U.S. Ghosh (IUAC, New delhi), A.K. Mondal (Bolpur College, WB) and S. Rai (Malda College, WB) is gratefully acknowledged.

References

[1] C.E. Svensson *et al.*, Phys. Rev. Lett. **82**, 3400 (1999).
[2] L.L. Andersson *et al.*, Eur. Phys. J. A **30**, 381 (2006).
[3] L.L. Andersson *et al.*, Phys. Rev. C **79**, 024312 (2009).
[4] C.H. Yu *et al.*, Phys. Rev. C **62**, 041301(R) (2000).
[5] B. Mukherjee *et al.*, Phys. Rev. C **64**, 024304 (2001).
[6] S. Rai *et al.*, Phys. Rev. C **102**, 064313 (2020).
[7] S. Rai *et al.*, Int. J. Mod. Phys. E **25**, 1650099 (2016).
[8] M. Honma *et al.*, Phys. Rev. C **80**, 064323 (2009).
[9] B.A. Brown, A.F. Lisetskiy, private communication; and Ref. [28] in Cheal *et al.*, Phys. Rev. Lett. **104**, 252502 (2010).
[10] M. Honma *et al.*, Eur. Phys. J. A **25**, s01 499 (2005).
[11] B. A. Brown and W. D. M. Rae, Nucl. Data Sheets **120**, 115 (2014).
[12] ENSDF database.