Revisiting the alternating-parity structures in ^{218}Ac

Dhananjaya Sahoo[1],[*] A. Y. Deo[1],[†] Shabir Dar[1], Madhu[1], Khamosh Yadav[2], S. S. Tiwary[3], R. Palit[4], S. K. Tandel[5], P. Dey[4], Biswajit Das[4], Vishal Malik[4], A. Kundu[4], A. Sindhu[4], S. V. Jadhav[4], B. S. Naidu[4], and A. V. Thomas[4]

[1]*Department of Physics, Indian Institute of Technology Roorkee, Roorkee - 247667, INDIA*
[2]*Department of Physics, Indian Institute of Technology Ropar, Rupnagar - 140001, INDIA*
[3]*Department of Physics, School of Basic Sciences,*
Manipal University Jaipur, Jaipur - 303007, INDIA
[4]*Department of Nuclear and Atomic Physics, Tata Institute of Fundamental Research, Mumbai - 400005, INDIA and*
[5]*Department of Physics, School of Natural Sciences,*
Shiv Nadar Institution of Eminence, Gautam Buddha Nagar - 201314, INDIA

Introduction

The phenomenon of octupole correlations in the transitional nuclei beyond the doubly-magic ^{208}Pb has been a topic of considerable interest for the past few decades [1, 2, 3]. The presence of single-particle intruder orbitals near the Fermi surface separated by $\Delta j = \Delta l = 3\hbar$ i.e. ($\pi i_{13/2}$ and $\pi f_{7/2}$) and ($\nu g_{9/2}$ and $\nu j_{15/2}$) and the interaction between them result in long-range octupole correlations between the valence nucleons [4, 5]. Experimental signatures of octupole correlations include the presence of interleaved positive- and negative-parity bands connected via enhanced $E1$ transitions [4, 5]. The strong octupole correlations lead to the manifestation of reflection-asymmetric stable pear shapes in nuclei [4, 5]. As one moves away from the region of strong octupole correlations towards the shell closures, single-particle degrees of freedom start contributing to the structural properties of nuclei, in addition to the collective mode of excitations, resulting in more complex level structures. The nuclei in the Ra-Th region ($A \sim 220$) are key examples of transitional nuclei, illustrating the evolution of structure from single-particle excitations to strong octupole correlations [4].

The relationship between parity-doublet structures and the emergence of reflection-asymmetric shapes was investigated in all the trans-lead $N = 129$ isotones [1, 2, 3, 6]. It was observed that ^{216}Fr ($Z = 87, N = 129$) is the lightest doubly odd nucleus to exhibit alternating parity structures [6]. Similar band structures were also reported in ^{217}Ra [3, 7] and ^{218}Ac [1]. In fact, ^{218}Ac was identified as the first transitional nucleus to exhibit parity-doublet structures [6]. Furthermore, the level structures in light actinium isotopes have significant dependency on the valence nucleons outside the shell closures. For example, the yrast and near-yrast structures in ^{215,217}Ac [8, 9] are governed by single-particle excitations, while the heavier Ac isotopes (i.e $^{219-221}$Ac) exhibit collective octupole correlations and quadrupole deformation, resulting in alternating-parity bands with irregular energy vs. spin behavior [10, 11, 12]. Thus, ^{218}Ac, lying between the above mentioned isotopes, requires a detailed spectroscopic investigation to understand the evolution of structure in the transitional region.

Experimental details

High-spin states in ^{218}Ac were populated using the ^{209}Bi(^{12}C, 3n)^{218}Ac heavy-ion fusion-evaporation reaction. The 72 MeV beam of ^{12}C, provided by the 14-UD Pelletron LINAC Facility (PLF) at TIFR, Mumbai, was bombarded on a self-supporting ^{209}Bi target of 4 mg/cm^2 thickness. The Indian National Gamma Array (INGA) was utilized to detect the γ rays from deexcitation of the residual nuclei. The array consisted of 18 Compton suppressed High-purity Germanium (HPGe) clover detectors which were positioned at seven different angles with respect to the beam direction. The time-stamped digital data were collected with two- and higher-fold coincidence condition using a 12-bit 100 MHz PIXIE-16 digitizer modules developed by XIA-LLC, USA [13]. The calibrated data were written into ROOT Tree format using a code developed at IIT Roorkee which is based on the code Multi-pARameter time-stamped based COincidence Search (MARCOS) [13]. The data in ROOT Tree format were further sorted to

---

[*] Electronic address: dhananjaya.ph@sric.iitr.ac.in
[†] Electronic address: ajay.deo@ph.iitr.ac.in

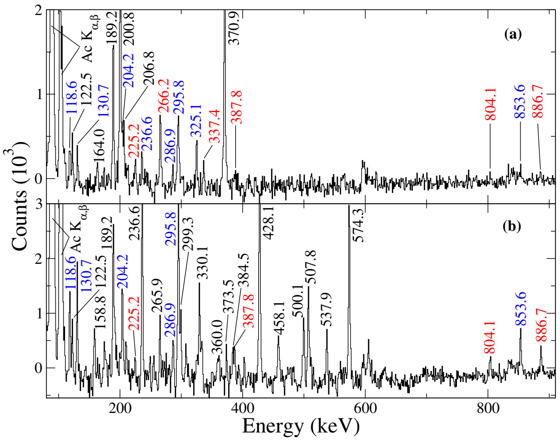

FIG. 1: Coincidence γ-ray spectra illustrating the transitions in the double gate of the (a) 574.3- and 428.1-keV , and (b) 370.9- and 200.8-keV transitions. The transitions in blue color are those for which the placement was uncertain in the earlier studies and confirmed in the present work. The new transitions identified in the present work are shown in red color.

generate various two- and three-dimensional histograms compatible with ROOT and RADWARE packages.

Results and Discussion

The previously reported level structures of ^{218}Ac have been revisited which consisted of three alternating-parity sequences [1]. In addition to the already known information, several new transitions feeding the high-spin states of ^{218}Ac have been identified. Figure 1 illustrates the prompt transitions in the double gate of the (a) 574.3- and 428.1-keV , and (b) 370.9- and 200.8-keV transitions. A new cascade of the 387.8- and 886.7-keV transitions is observed in coincidence with the 370.9- and 200.8-keV transitions as well as with all the low-lying transitions, which confirms its placement above the 200.8-keV transition in the level scheme. In addition, a new 266.2-keV transition is observed in the double gates of the 574.3- and 428.1-keV transitions (see Fig. 1(a)), and 574.3- and 200.8-keV transitions. However, this transition is not observed in the double gate of the 574.3- and 370.9-keV transitions, which indicates that the 266.2-keV transition may be placed in parallel to the 370.9-keV transition. Similar coincidence relationships are utilized for confirming the placements of previously known and newly identified transitions in the level scheme. The spin-parity of the states are established on the basis of R_{DCO} and linear polarization measurements. The excited states in the doubly-odd ^{218}Ac can be understood as the coupling of the odd proton in the $h_{9/2}, f_{7/2}$, and $i_{13/2}$ orbitals with the odd neutron in the $g_{9/2}, i_{11/2}$, and $j_{15/2}$ orbitals [1]. Since ^{218}Ac lies in the transitional region, most of its structural properties are qualitatively described in terms of the collective degrees of freedom [1]. Thus, the coupling between the single-particle configurations and the vibrational degrees of freedom (quadrupole and octupole states) plays an important role in governing the underlying structure of the low-lying states [1]. The detailed experimental results along with the theoretical interpretation will be presented during the symposium.

Acknowledgments

The technical assistance from Target Laboratory, INGA and PLF staffs of TIFR during the course of experiment is highly appreciated. DS acknowledges the financial support from MHRD, India. AYD would like to acknowledge the the financial support by DST-SERB vide grant no. CRG/2020/002169. This work is supported by the Department of Atomic Energy, Government of India (Project Identification No. RTI 4002), and the Department of Science and Technology, Government of India (Grant No. IR/S2/PF-03/2003-II).

References

[1] M. E. Debray *et al.*, Nucl. Phys. A **568**, 141-168 (1994).
[2] Pragati *et al.*, Phys. Rev. C **97**, 044309 (2018).
[3] Madhu *et al.*, Phys. Rev. C **108**, 014309 (2023).
[4] I. Ahmad and P. A. Butler, Annu. Rev. Nucl. Part. Sci. **43**, 71 (1993).
[5] P. A. Butler and W. Nazarewicz, Rev. Mod. Phys. **68**, 349 (1996).
[6] M. E. Debray *et al.*, Phy. Rev. C **41**, R1895 (1990).
[7] N. Roy *et al.*, Nucl. Phys. A **426**, 379-398 (1984).
[8] D. J. Decman *et al.*, Z. Phys. A **310**, 55-59 (1983).
[9] D. J. Decman *et al.*, Nucl. Phys. A **436**, 311 (1985).
[10] F. Cristancho *et al.*, Phy. Rev. C **49**, 663 (1994).
[11] N. Schulz *et al.*, Z. Phys. A - Had. and Nucl. **339**, 325-334 (1991).
[12] M. Aiche *et al.*, Nucl. Phys. A **567**, 685-700 (1984).
[13] R. Palit *et al.*, Nucl. Instrum. Methods Phys. Res. A **680**, 90 (2012).