Nuclear structure investigations in transitional region around doubly-magic ^{208}Pb

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1. Introduction

The shape and structure of atomic nuclei are governed by the interactions between the valence nucleons and available orbitals near the Fermi surface. The nuclei near doubly-magic ^{208}Pb are predominately influenced by the single-particle excitations, while collective quadrupole and octupole excitations dominate the structure of nuclei near $A \sim 220$. Transitional nuclei, which lie in between the extremes of spherical and deformed nuclei, display diverse structural phenomena originating from the competition between these basic modes of excitations. This thesis work is based on investigating the structure of two transitional nuclei, viz. ^{216}Fr and ^{217}Ra ($N =$ 129 isotones), which lie near the lower boundary of octupole collectivity in the trans-lead region. ^{216}Fr is the lightest nucleus in this mass region which exhibits fingerprints of octupole correlations. However, it is interesting to note that the low-lying yrast states in this nucleus are well interpreted in terms of the spherical shell model. Furthermore, it was also noted that the parity-doublet structures, which are signatures of octupole correlations in odd-A and doubly-odd nuclei, have been established in all the $N = 129$ isotones with 87 $\leq Z \leq 90$ except for ^{217}Ra. Thus, comprehensive studies focused on investigating the high-spin states and isomerism in ^{216}Fr and ^{217}Ra were required for understanding how the nuclear structure evolves with the nucleon number, excitation energy and angular momentum in the transitional region.

2. Experimental Details

High-spin states in ^{216}Fr and ^{217}Ra were populated using ^{208}Pb(^{11}B, 3n)^{216}Fr and ^{208}Pb(^{12}C, 3n)^{217}Ra reactions, respectively, at Inter University Accelerator Centre, New Delhi. The Indian National Gamma Array (INGA), which comprised of Compton-suppressed clover HPGe detectors and Low Energy Photon Spectrometer, was used to detect the γ rays emitted in the de-excitation process of the residual nuclei. The data were acquired using CAMAC and VME based data acquisition systems. The calibrated data were written into a ROOT tree format and further sorted into various histograms compatible with ROOT and RADWARE. The properties of the excited states were obtained by employing several γ-ray spectroscopic techniques which include establishing the coincidence relationships between the observed γ rays, determining their multipolarities and extracting the half-lives of the isomeric states using centroid-shift and decay curve analyses. More details pertaining to the experimental and data analysis techniques can be found here [1, 2].

3. Results and Discussion

In the first work of this thesis, the structure of ^{216}Fr was investigated by searching for isomeric states in this transitional nucleus [1]. An $(11)^+$ isomer, which was known in several doubly-odd nuclei in the trans-lead region, has been identified for the first time in ^{216}Fr. Figure 1 illustrates the centroid-shift analysis for determining the half-life of the $(11)^+$ state. Large-scale shell-model calculations were performed for the states related to the decay path of the isomer. The deviation between the calculated and experimental reduced transition probabilities suggests that the effects other than single-particle degrees of freedom also play a significant role in the structure of these states. Additionally, two more isomers with $T_{1/2} = 7.8(14)$ and 89(9) ns

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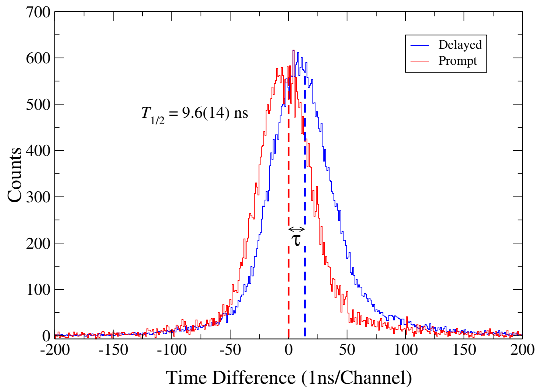

FIG. 1: Centroid-shift technique used for determining the half-life of the (11^+) state in ^{216}Fr .

have been identified in ^{216}Fr and are proposed to be placed above the already established alternating parity sequences. The presence of isomers at higher excitation energies suggests a pronounced change in the structure above the (18^+) state in this nucleus.

In the high-spin study of ^{217}Ra, the level scheme has been extended with the addition of 23 new transitions [2]. Also, the placement and ordering of 15 transitions, which were either inconsistent or uncertain in the earlier studies, have been confirmed. A new negative-parity sequence is established at low excitation energies which confirms the presence of parity-doublets in this nucleus. The addition of this new sequence results in striking similarity of the low-lying level structure in ^{217}Ra with those of its $N = 129$ isotones (^{216}Fr, ^{218}Ac and ^{219}Th). A comparison of the observed features of the parity-doublet structures in ^{217}Ra with the properties of the similar bands in neighboring nuclei (see Fig. 2) and the predictions of the reflection asymmetric triaxial particle rotor model (RAT-PRM) calculations suggest that ^{217}Ra exhibits an intermediate behavior between the extremes of vibrational and octupole-deformed nuclei. It was also noted that the alternating parity sequences terminate at $I^{\pi} = 29/2^-$ in ^{217}Ra and the states lying above seem to originate from single-particle excitations.

Thus, the extensive studies of high-spin states and isomers in these $N = 129$ isotones (^{216}Fr and ^{217}Ra) reveal that the single-particle and collective modes of excitations govern the structure at different excitation energies and angular momentum in these transitional nuclei.

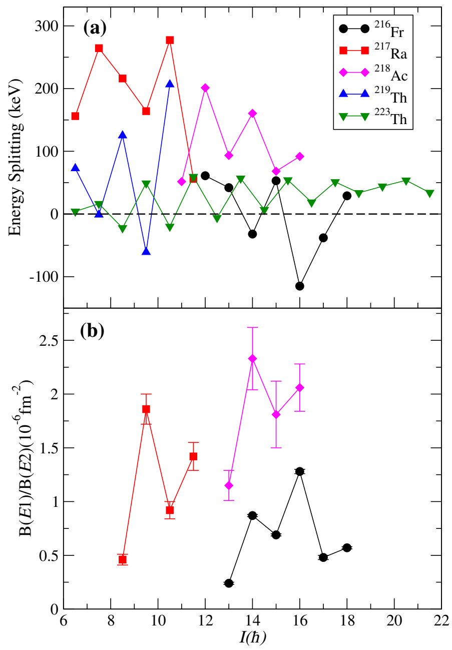

FIG. 2: Comparison of (a) energy splitting and (b) B$(E1)$/B$(E2)$ ratios versus initial spin for the transitions of $s = +i$ band in ^{217}Ra with $N = 129$ isotones [2].

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References

[1] Madhu *et al.*, Phys. Rev. C **105**, 034308 (2022), and references therein.

[2] Madhu *et al.*, Phys. Rev. C **108**, 014309 (2023), and references therein.