Spectroscopic study of unnatural parity states in ^{43}Ca

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Introduction

Gamma spectroscopy is a powerful tool for probing the structure of atomic nuclei. Advances in detection and data acquisition systems have enabled the exploration of nuclei at higher excitation energies and momenta, unveiling new insights into nuclear behaviour. One particularly intriguing area of study is the region near the doubly magic nucleus with N = Z = 20. In these nuclei, we observe a fascinating coexistence of single-particle and collective modes of excitation. In the upper sd shell, nuclei exhibit single-particle excitations at relatively low excitation energies [1]. However, as excitation energy and angular momentum increase, collective phenomena begin to play a significant role in shaping the nuclear structure. Nuclei within the $1f_{7/2}$ shell are especially captivating, displaying a similar interplay of single-particle and collective behaviours, making them a focus of intense study.

^{43}Ca is an odd-even (N = 23, Z = 20) nucleus in the lower pf shell. In our recent work, we have investigated the high-spin structure of the ^{40}K [2], which shows mostly single-particle behaviour at lower excitation energy, and the signature of collective excitation at relatively higher excitation energy was established based on their calculated wave functions. Similar structural behaviour is also identified in ^{33}S, ^{34}Cl, ^{35}Cl, ^{37}Ar, and ^{38}K [1]. So, one may also expect the interplay between single-particle and collective excitations in ^{43}Ca. The structure of ^{43}Ca was studied in various experiments [1], including heavy-ion fusion evaporation reactions [3]. ^{43}Ca nucleus was previously studied by P. Benarczyk *et al*. [3] through heavy-ion reaction. Our primary motivation is to explore the unnatural parity states of ^{43}Ca and investigate the evolution of collectivity with excitation energy.

Experimental Details

High-spin states of ^{43}Ca were populated via ^{27}Al (^{19}F, 2pn) ^{43}Ca nuclear reaction at 68 MeV. This experiment was conducted at the IUAC, New Delhi. A thick ^{27}Al target (0.43 mg/cm²), with gold backing (11.4 mg/cm²) was used. For γ-ray detection, we utilized the INGA facility, consisting of 12 Compton-suppressed clover detectors. These detectors were strategically positioned at four different angles relative to the beam axis: 148° (4), 90° (4), 57° (1), and 32° (3). Data acquisition and analysis were carried out using NiasMARS [4]. This tool generated both angle-independent symmetric and angle-dependent asymmetric $E_\gamma - E_\gamma$ matrices, which were subsequently analyzed using the INGASORT [5] sorting program. For the energy calibration of the clover detectors, we employed online gammas ranging from 300 to 4000 keV. Relative efficiency calibration was performed using ^{152}Eu and ^{66}Ga radioactive sources.

Result and Discussion

The level scheme of ^{43}Ca is extended up to 8 MeV in the present work. We have added seven new transitions and two new levels to the

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existing level scheme [3]. Our study identified one level and six transitions previously observed in light-ion-induced experiments [1]. The level scheme was studied based on the coincidence relationship, relative intensities, R_{DCO}, R_{ADO}, and Δ_{IPDCO} values of the γ transitions (Fig. 1).

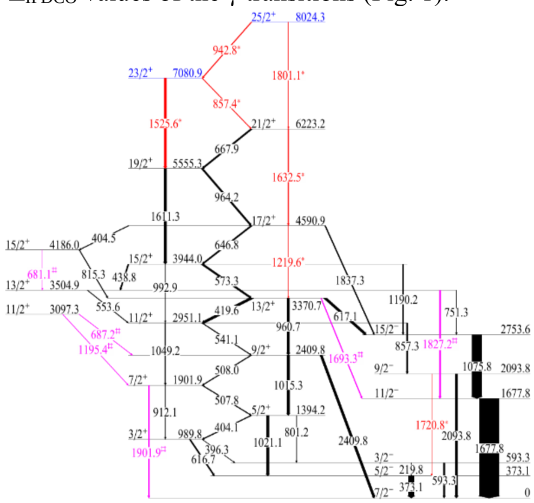

Fig 1: Partial level scheme of ^{43}Ca. Newly observed gammas are marked by ***(red)**. Gammas indicated by **# (magenta)** are observed in light-ion-induced reactions. New levels are indicated by blue line.

The measurement of DCO was carried out to confirm or assign the spins of the levels in ^{43}Ca. The DCO measurement for a few transitions could not be carried out due to insufficient statistics. As a result, ADO measurements were conducted to deduce their multipolarities. From these findings, we have tentatively assigned or confirmed the spins of various levels, as illustrated in Fig. 1. To determine the γ-ray multipole mixing ratios (δ), we compared our experimental R_{DCO} values with theoretical predictions calculated using the computer code ANGOR [6]. Additionally, we performed IPDCO measurements to identify the electric and magnetic character of the transitions.

In our current work, we have successfully confirmed the spin and parity assignments of the $19/2^+$ and $21/2^+$ states in ^{43}Ca. Furthermore, we have extended the level scheme up to $J^\pi = 25/2^+$ state, representing the band-terminating state corresponding to $(1d_{5/2})^{-1} \otimes (1f_{7/2})^4$ configuration.

LBSM calculations for ^{43}Ca were performed using OXBASH [7] code, considering the valence orbitals $1d_{5/2}$, $1d_{3/2}$, $2s_{1/2}$, $1f_{7/2}$, $1f_{5/2}$, $2p_{3/2}$, and $2p_{1/2}$ above ^{16}O core, with 27 valence particles. For negative parity states the particle configuration is $(sd)^0 - (pf)^3$. For positive parity states we allow only one particle to excite from *sd* to *pf* shell. The particle configuration for the truncation is therefore $(sd)^{-1} - (pf)^4$. The theoretical energies are in good agreement with experimental values (Fig. 2). We have also calculated the transitions probabilities and compared them with their experimental values wherever available.

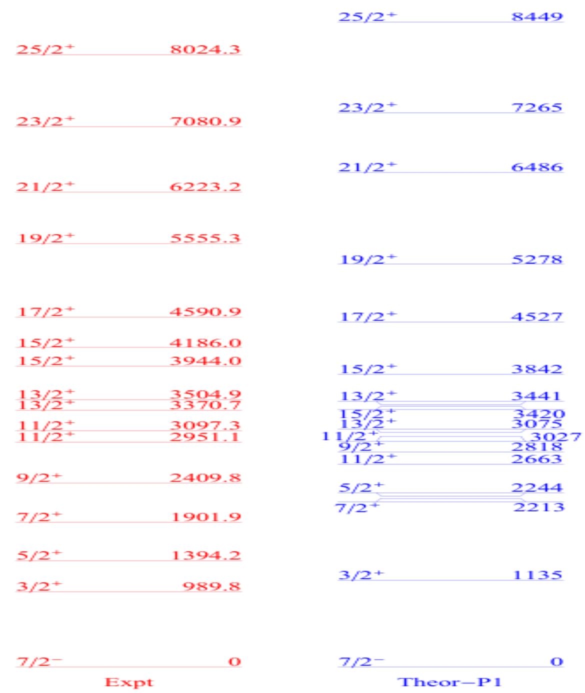

Fig 2: Comparison between experimental and shell model energies for positive-parity states.

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