Transfer reaction for the study of α-cluster states in ^{54}Cr

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Introduction

Emergence of α-clustering in nuclei and its impact on their various properties, particularly starting from light nuclei within the nuclear table [1] remains a topic of contemporary interest. The concept of clustering has been observed since the early days of nuclear physics, where an α-particle can serve as the fundamental building block for certain nuclei. The α-cluster model serves as a valuable tool to elucidate significant aspects of nuclear behavior, including electromagnetic transition strength, α-decay width, and α-particle scattering data. Moreover, it simplifies the computationally challenging task by reducing the degrees of freedom. In lighter nuclei with mass numbers less than A = 40, α-clustering is a prominent characteristic in numerous states [2–4]. In the fp-shell region, ^{44}Ti has been extensively studied with the interpretation of α + core (^{40}Ca) configurations. Recently, M. A. Souza and H. Miyake proposed that ^{46}Cr and ^{54}Cr are the most favorable even-even Cr isotopes for the α + core configuration [5]. Hence the cluster structure study of ^{54}Cr is important with available stable projectile-target combinations.

In this present work, we have populated the excited states in ^{54}Cr via the α-transfer to ^{50}Ti nucleus. The reactions were studied through particle-γ coincidence measurements. Different excited states of ^{54}Cr have been identified with triton gate of $E_t > 17.5$ MeV. Along with the yrast states, several low-lying non-yrast states were found through this reaction. The α + core spectroscopic factors for the observed excited states have been obtained.

Experimental details

The excited states of ^{54}Cr were populated via an α-transfer reaction, specifically ^{50}Ti(^{7}Li, t)^{54}Cr, using 20 MeV beam provided by the 14UD Pelletron Linac accelerator Facility (PLF) at TIFR, Mumbai, India. For this experiment, a self-supporting target of ^{50}Ti with a thickness of approximately 1.48 mg/cm^2 was employed. The de-exciting γ-rays of residual nuclei were detected by the Indian National Gamma Array (INGA) at TIFR, consisting of 17 Compton-suppressed clover HPGe detectors at different angles with respect to the beamline. To detect outgoing charged particles, we utilized an array of thirteen CsI(Tl) detectors. Additionally, a Si surface barrier detector (monitor) was incorporated to detect scattered beam particles for cross-section calculations. The signals from the individual CsI(Tl) detectors and each crystal of the clover detectors were collected using a total of six 12-bit 100 MHz PIXIE-16 modules. The CsI(Tl) detectors were calibrated using the triton energy spectrum from the reaction ^{12}C(^{7}Li, t)^{16}O at a beam energy of 20 MeV. For the calibration of the clover HPGe detectors, we employed a mixed ^{133}Ba-

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^{152}Eu source.

Results and discussion

The collected experimental data have been sorted by a MultipARameter time-stamped based COincidence Search (MARCOS) code, developed at TIFR. The particle-γ matrix files and ROOT NTuple with two- and higher-fold coincidence events have been generated. From each raw pulse of the CsI(Tl), the QDC-short and QDC-long have been calculated. The 2D particle identification spectrum has been generated in coincidence with any of the clover detectors. A two-dimensional spectrum of QDC-short vs QDC-long for 34° CsI(Tl) detectors has been shown in Fig. 1. Proton-, triton-, and alpha-band have been identified in the spectrum. The γ spectrum of the clover detectors has been obtained and cleaned by applying the 2d gate to the particle spectrum. In the present heavy-ion collisions, various reaction channels become energetically favored. The complete fusion evaporation reaction has a dominant cross-section. Specifically, nuclei such as ^{54,55}Mn and $^{53-55}$Cr are substantially populated through different pathways, including ($3n$), ($2n$), ($p3n$), ($p2n$), and (pn) complete fusion evaporation channels. Moreover, the nucleus ^{54}Cr can also be generated through the α-cluster transfer to ^{50}Ti. In the incomplete fusion channel, the ^{54}Cr compound nucleus will be formed which subsequently undergoes de-excitation processes, leading to the production of $^{51-53}$Cr through multi-neutron (xn)-evaporation and $^{51-53}$V via (pxn) channels. In this work, along with yrast state (up to 8^+), multiple low-lying non-yrast 2^+ and 4^+ states of ^{54}Cr have been populated which are typically challenging to access through fusion evaporation reactions. The integrated transfer cross-sections for both the observed yrast and non-yrast states have been measured. We have then compared these measurements with calculations performed using Coupled Reaction Channels in the FRESCO framework, allowing us to extract α-core spectroscopic factors [6]. Our findings suggest moderate α-cluster structure for the yrast states of ^{54}Cr and the clustering effect reduces for the non-yrast states.

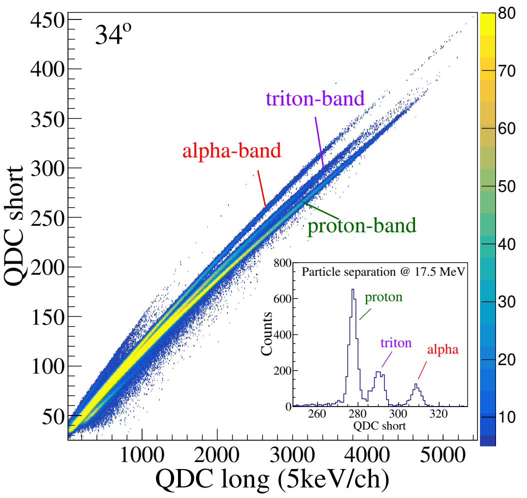

FIG. 1: The calibrated particle spectrum from a CsI(Tl) detector positioned at $\theta_{\rm lab}$ = 34° reveals distinct bands of light-charged particles, including protons, tritons, and -particles, as observed in the current measurement. Insets demonstrate a sharp differentiation between these particle types at an energy of 17.5 MeV.

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