K isomers in Hf isotopes

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Introduction

A large number of Hf (Z = 72) isotopes ranging from proton-rich (N = 98) to neutron-rich (N = 114) exhibit the presence of *K* isomers [1-6]. With an increase in neutron number, the neutron orbitals with relatively higher values of Ω are found to be adjacent to the Fermi level creating conditions which are ideal for the realization of *K* isomers in these well-deformed nuclei. Some of the most robust examples of *K* isomerism in the nuclear chart are found in Hf isotopes. The half-lives of these states range from a few nanoseconds up to 31 years. The extremely long-lived states attest to the conservation of the *K* quantum number while the shorter-lived ones provide insight into the mechanisms which significantly affect the *K* hindrance.

Isotopes along or on the neutron-rich side of the line of stability have been studied using lighter ions or through inelastic excitation or multi-nucleon transfer reactions. On the other hand, those on the proton-rich side have been primarily studied using heavy-ion beams. Building on our recent work on metastable states in the $A \approx 180$ and $A \approx 200$ regions [1,7-11], the present investigation is focused on lighter Hf isotopes which have been populated using an alpha beam allowing for the exploration of additional band structures in comparison to those established using heavy-ion beams.

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Experiment and data analysis

High-*K* states in $^{172-178}$Hf were populated using a 32-MeV alpha beam from the K-130 cyclotron at VECC, Kolkata, which was incident on a thick natural Yb target. The γ rays emitted from the excited states of the evaporation residues were recorded in coincidence using the INGA array consisting of 11 clover high-purity germanium (HPGe) detectors and 1 LEPS detector; a PIXIE-16 digitizer-based data acquisition system was utilized [12]. Gamma-ray coincidence events spanning a range of 4 μs were recorded. The data were sorted offline into a variety of histograms using the BiNDAS software package [13] and analysed using the RADWARE suite of programs [14]. The coincidence histograms include two- and three-dimensional symmetric energy ones with the requirement of different time periods for the coincidence window, and asymmetric ones including early-delayed and Directional Correlation of Oriented States (DCO) matrices.

Results and Discussion

A preliminary analysis of the data confirms the presence of *K*-isomeric states up to $I \approx 16\ \hbar$ in $^{172-178}$Hf established earlier [2-5]. It was possible to verify the reported half-lives of a few of these states in both even- and odd-mass Hf isotopes (see Figs. 1 and 2). Additionally, the high-*K* band members associated with these isomers could also be confirmed. An inspection of the $M1/E2$ branching ratios in the high-K bands enable their configuration assignments through a deduction of the intrinsic g factors; this analysis is in progress.

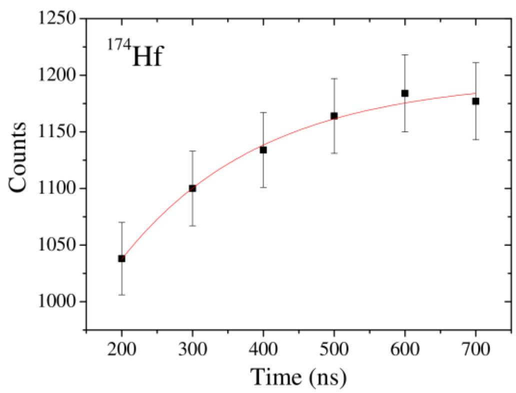

Fig. 1 Time distribution of integral counts from the decay of the $K^\pi = 6^+$, $T_{1/2}$ = 138 ns isomer in ^{174}Hf.

In the lighter Hf isotopes, where only some band structures have been established, the data appear to indicate significant scope for extending the level schemes in terms of identifying new sequences of transitions, particularly those built on two- and three-quasiparticle excitations. The symmetric and asymmetric histograms consisting of both prompt and delayed transitions are being analyzed towards this end.

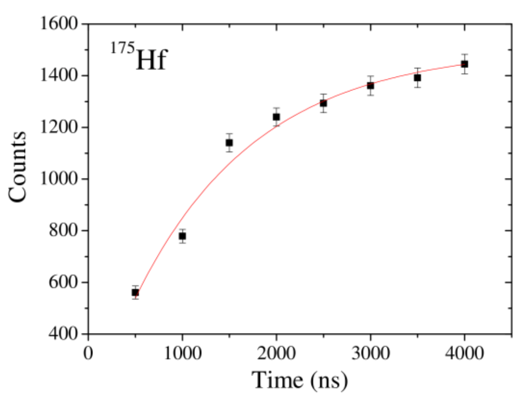

Fig. 2 Time distribution of integral counts from the decay of the $K^\pi = 19/2^+$, $T_{1/2}$ = 1.1 μs isomer in ^{175}Hf.

The present study is expected to enhance the knowledge of high-K structures and their underlying nucleonic configurations, thereby contributing to an improved understanding of the decay mechanisms, particularly in the case of states which may not lie along the yrast line. The variation of reduced hindrance as a function of excitation energy above the yrast line is being explored.

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