Observation of fast-feeding transitions and its implication in measured lifetimes for the states in $K^{\pi} = 15/2^-$ band in ^{51}Cr

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Introduction

^{51}Cr is a $f_{7/2}$ shell nuclei with neutron and proton numbers between the two magic numbers 20 and 28. Considering a ^{40}Ca core, the ^{51}Cr nucleus has the proton $f_{7/2}$ shell exactly half-filled with four protons and the neutron $f_{7/2}$ shell near shell closure with one neutron hole. This provides an ideal playground to study the interplay of single-particle and collective effects in this nucleus. This interplay is indeed a characteristic feature of the $f_{7/2}$ nuclei where it is manifested in deformed rotational structure at lower spins particularly for nuclei near the center of $f_{7/2}$ shell. The deformation then decreases with spin till there is complete non-collective alignment at the band terminating state. Isotopes of chromium and vanadium with N~Z have been studied in great detail [1,2] and have brought out these features that have been explained through both the shell model and the collective model. However experimental data in ^{51}Cr is sparse and have many questions that were left unanswered in the previous works. The level structure of this nucleus has been found to have band like structures with band heads at $K^{\pi} = ½^-$, $7/2^-$ and $15/2^-$. The aim of the present work was to investigate these bands and also explore the existence of other such bands. Accurate lifetime measurements that are crucial for understanding of the underlying structure up to and beyond band termination are not available and has been one of the major motivations of this work. The much-anticipated fast side-feeding transitions [3] to explain the lifetimes of the yrast levels belonging to the states in the $K^{\pi} = 15/2^-$ band were expected to be observed with a better and more powerful array of detectors than what was available in the seventies and eighties when the last experiments to explore this nucleus were carried out. [3] The latest work on this nucleus was reported by Cameron *et al*. where ^{40}Ca(^{14}N,3p) and ^{27}Al(^{27}Al,2pn) reactions were used with a moderate array of three to five Ge detectors and a NaI multiplicity filter [3].

Experimental details

High spin states in ^{51}Cr were populated using the ^{27}Al (^{28}Si, 3pn) ^{51}Cr reaction at the BARC-TIFR Pelletron facility. The ^{28}Si beam impinging on the target was of energy 100 MeV. The target consisted of a ~750 μg/cm^2 thick Al foil with a 14.8mg/cm^2 thick layer of Au backing. The de-exciting γ-rays were detected by the Indian National Gamma Array (INGA), then consisting of twenty Compton-suppressed clover Ge detectors, two each at 23^0 and 115^0, three each at 40^0, 65^0, 140^0 and 157^0 and four at 90^0 with respect to the beam direction. The data was acquired using a digital data acquisition system [3] that employed Pixie-16 modules from XIA-LLC, USA. Two and higher fold time-stamped coincidence events were recorded and subsequently analyzed offline, using the RADWARE and LINESHAPE software packages.

Results and Discussions

The level structure of ^{51}Cr has been substantially extended through the addition of new transitions in each of the $K^{\pi} = ½^-$, $7/2^-$ and $15/2^-$ bands. A new band structure with band head at $K^{\pi} = 19/2^-$ is proposed. Several

transitions connecting the states in this band to the states in the 3qp K^{π} = 15/2$^-$ band affirm the placement of this band and the spin-parity of the levels of this band. These inter-band transitions are the fast side-feeding to the yrast 17/2$^-$ and 19/2$^-$ levels anticipated by Cameron *et al.* to explain the lifetimes of the yrast levels. Lifetime measurements were carried out for yrast levels up to and beyond the band-terminating state 23/2$^-$ through Doppler Shift Attenuation Method using the LINESHAPE code (see Fig. 1). The corresponding reduced transition probabilities were determined.

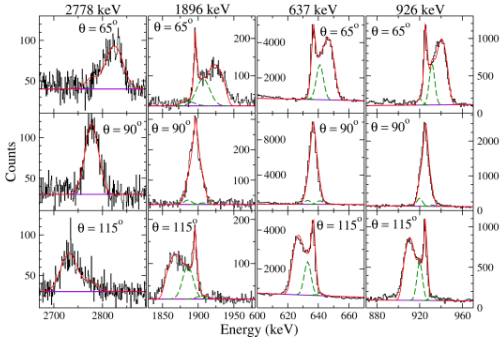

Fig. 1: Extraction of lifetimes using DSAM with LINESHAPE code

Large scale shell model calculation with ^{40}Ca core in the full *fp*-model space has been carried out to interpret the level structure. The three effective interactions GXPF1A, KB3G and FPD6 that were developed for this mass region were used in code NuShellX@MSU [5] for calculating the energy levels, lifetimes, transition probabilities and quadrupole moments in this nucleus. The GXPF1A and KB3G interactions were found to successfully reproduce the experimental observables. The low-lying yrast states such as 15/2$^-$ and 17/2$^-$ have major contribution from outside $f_{7/2}$ shell. At yrast 19/2, however the dominant contribution is from $f_{7/2.}$ A sudden decrease in B(E2) value is observed experimentally and is also predicted by theory at this spin. This indicates a shape change. A comparison between the variation of the B(E2)$^{1/2}$ values with spin between ^{51}Cr and ^{49} V has been made along the yrast sequence (see Fig. 2). The B(E2)$^{1/2}$ is proportional to the deformation. It is clear from the plot that the B(E2)$^{1/2}$ values are higher for ^{49}V compared to ^{51}Cr for the same spins (see Fig. 2). This suggests that it is the neutron numbers close to the mid $f_{7/2}$ shell rather than the protons that drive the yrast states towards more deformation in the $f_{7/2}$ shell nuclei.

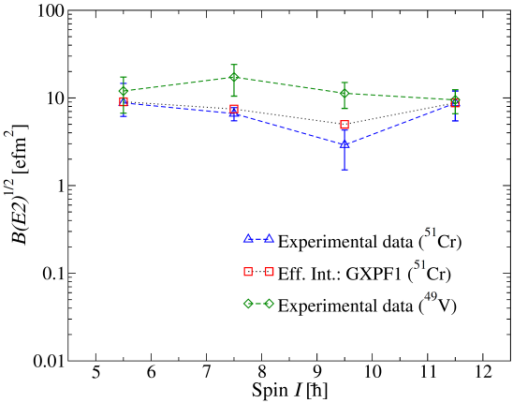

Fig. 2 Variation of B(E2)$^{1/2}$ with spin along the yrast sequence for ^{51}Cr and ^{49}V.

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