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A high spin isomer in ^{153}Eu

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Abstract. A search for new isomers of nanosecond lifetimes were carried out in ^{153}Eu via the ^{150}Nd(^{7}Li,xnγ) reaction. The single particle angular momentum alignment and dynamical moment of inertia estimated from the experimental data indicate a configuration change at rotational energy $\hbar\omega \sim 0.30$ MeV. A decrease of B(E2) values is also observed at the same frequency. An isomeric level is identified at an excitation energy of 3100 keV (J^{π}=35/2^{-}) which corresponds to this frequency. The lifetime of the level is found to be 8.6± 1.3 nanosecond.

PACS. 23.20.Lv Gamma transitions and level energies – 21.10.Tg Lifetimes – 27.70.+q $150 \leq A \leq 189$

1 Introduction

Life time measurements are unique indicators of the associated microscopic structure of the observed nuclear level sequences. Further high spin isomers are of special interest as they provide an insight into the interplay between the collective and noncollective degrees of freedom [1]. In the rare earth region for nuclei with Z=60-70 and N=82-92 several authors have reported the presence of isomeric states with I>10 [2-4]. A high spin isomer is normally observed in a nucleus with a few nucleons outside the closed core. The shell structure generates an irregular yrast line and the decay of levels is possible only via noncollective many particle or high multipolarity transitions. It is well known that the reduced quadrupole transition matrices i.e. B(E2) values significantly decrease in the neighbourhood of backbending which is interpreted in terms of a shape change from prolate to oblate due to the addition of the angular momenta of a pair of $i_{13/2}$ quasi neutrons [5].

The nucleus ^{153}Eu (Z=63, N=90) lies in the transitional region. In this nucleus the signature of collective degrees of freedom is predominant in the low energy excitations [6,7]. In the neighbourhood of ^{153}Eu high spin isomers were observed in odd-A ^{149,151}Sm nuclei [3,4]. However, there is no report of high spin isomer in N=90 nuclei in the literature. It is therefore interesting to explore the possible existence of high spin isomeric states in the region of ^{153}Eu nucleus.

2 Experiment

The nucleus ^{153}Eu was populated via the ^{150}Nd(^{7}Li, 4n) ^{153}Eu reaction. 36 MeV ^{7}Li beam was provided by the 15UD pelletron accelerator of the Nuclear Science Centre (NSC), New Delhi. The Gamma-Detector Array (GDA) was used to detect the γ-γ coincident events. At the time of this experiment the GDA consisted of 6 Compton suppressed HPGe detectors, and a 14 element BGO multiplicity filter. The target material, Nd-oxide powder(^{150}Nd enriched to ~96.6%) is difficult to handle and therefore had to be centrifuged on the 1mm thick kapton backing foil. The details of the target preparation was reported elsewhere [3]. The target was about 4mg/cm^{2} thick.

The electronic set-up and the data-acquisition system was designed to accept events with a minimum multiplicity of two Ge detectors firing within 40ns. The list mode data were recorded onto magnetic tapes for a detailed off-line analysis. These data consisted of energy and timing information coming from the detectors in coincidence. The lower level discriminator for the energy was set ~30 keV. The conventional Time-to-Digital Converters (TDCs) were used to measure the timing information [8]. The TDCs were kept at the common start mode. The two-fold coincidence logic signal of all the detectors i.e the master gate was used to generate the common start pulse (T_{ref}). The Compton supressed signal of each detector provided the individual stop signal (T_i, i=1..6). The output of each TDC channel was proportional to T_{ref} -

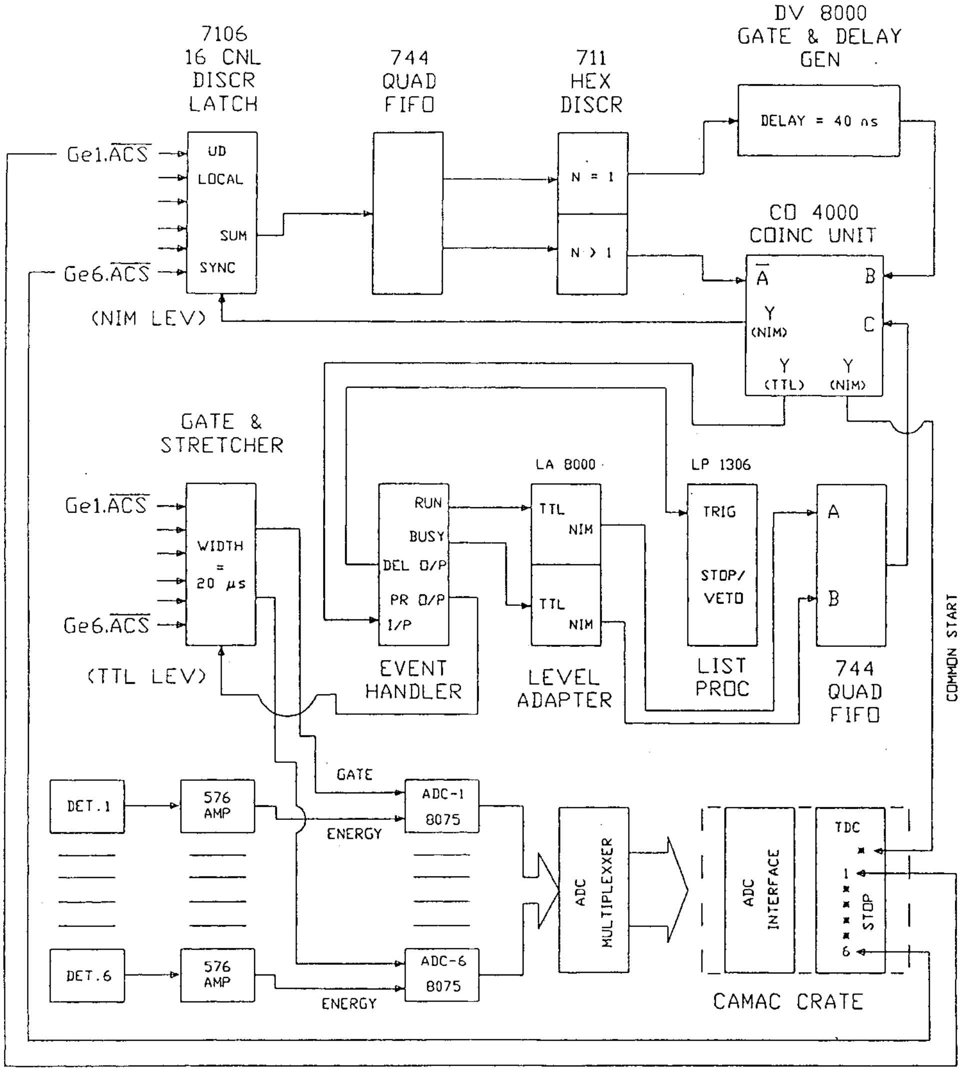

Fig. 1. Block diagram of electronic set-up for time measurement

T_i,(i=1..6). The block diagram of the relevant part of the electronic set-up is shown in Fig. 1.

During analysis all the detectors were software gain-matched. The data were then distributed between two pseudo detectors D_i and D_j and stored as a two-dimensional histogram to extract coincident information through conventional analysis technique. The TDCs were corrected for energy dependent walk and also mis-alignment of individual channels [9]. On the subtraction of the common signal T_{ref} the timing between any two coincident detectors was obtained.

3 Results and discussions

The coincidence spectra gated with 575 and 635 keV γ-rays are shown in Fig. 2. The level scheme for ^{153}Eu as obtained from the present study has been reported elsewhere [10,11] and the relevant part required for the present discussion is shown on the right hand side of Fig. 3. The processed TDC spectrum was projected out by setting appropriate gates on pairs of γ-rays. Each pair of γ-ray was chosen from the level scheme as feeding and decaying the same level so that the projected time spectrum from each such pair gives the information of the lifetime of the level involved. The prompt component was obtained by choosing as gates two γ-rays above and below the isomeric state to project the total time distribution. Further the time distribution of the pair of γ-ray, the first lying immediately above (before spectrum) and the second lying immediately below (after spectrum) the isomeric state, was also projected from where the lifetime was extracted. In this process a new high spin isomer has been identified in the cascade γ-rays of the negative parity band at $J^{\pi}=35/2^{-}$. The results of such a procedure are illustrated in Fig. 3.

The total time distribution was analyzed using the code RESFIT [12]. The before and after spectra were fitted using a single prompt gaussian component and a single exponential decay component. This procedure was repeated for several combinations of gates and the FWHM were obtained for each prompt peak. The average time distribution and errors for the prompt component has been computed from FWHM with the gates of γ-energy greater than 500 keV. The value obtained is 12.4±1.8ns . The

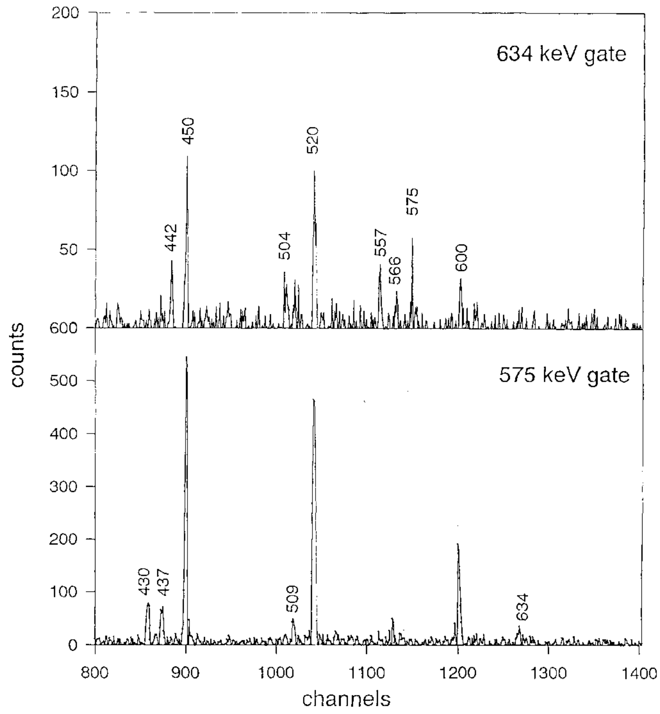

Fig. 2. Coincidence spectra gated with 575 keV and 634 keV γ-rays

TAC spectra gated with 635 ($39/2^- \rightarrow 35/2^-$) and 600 keV ($35/2^- \rightarrow 31/2^-$) feeding and decaying from 3100 keV level and 635 and 575 ($31/2^- \rightarrow 27/2^-$) keV γ transitions feeding 3100 keV and decaying from the 2500 keV levels of negative parity band respectively show a delayed component and have been fitted. The results obtained are plotted with the experimental data and shown in Figs. 3a & b. The lifetime for the J^π=35/2$^-$ level thus extracted from such a procedure is found to be 8.6ns. The fitting errors were determined in each case and the average fitting error is found to be 1.3ns. Similarly the prompt peak shown in Fig. 3c has been fitted and its time distribution has been found to be 12.2±1.9ns. This distribution is then normalised to the data of Fig. 3b and shown as dotted curve. A search for the origin of this isomer other than the 3100 keV level of the negative parity band of ^{153}Eu has been carried out which produced a negative result. Therefore we quote a lifetime of 8.6(1.3)ns for the level J^π=35/2$^-$.

Such a high spin isomer is possible if there is a shape change or a configuration change in this spin region. In either case the overlap between the initial and final wavefunction becomes less and subsequently there is a decrease in the B(E2) value corresponding to an appreciably large lifetime [13]. The reduction in B(E2) value is reflected in the ratio of the intensities of M1 and E2 transitions from

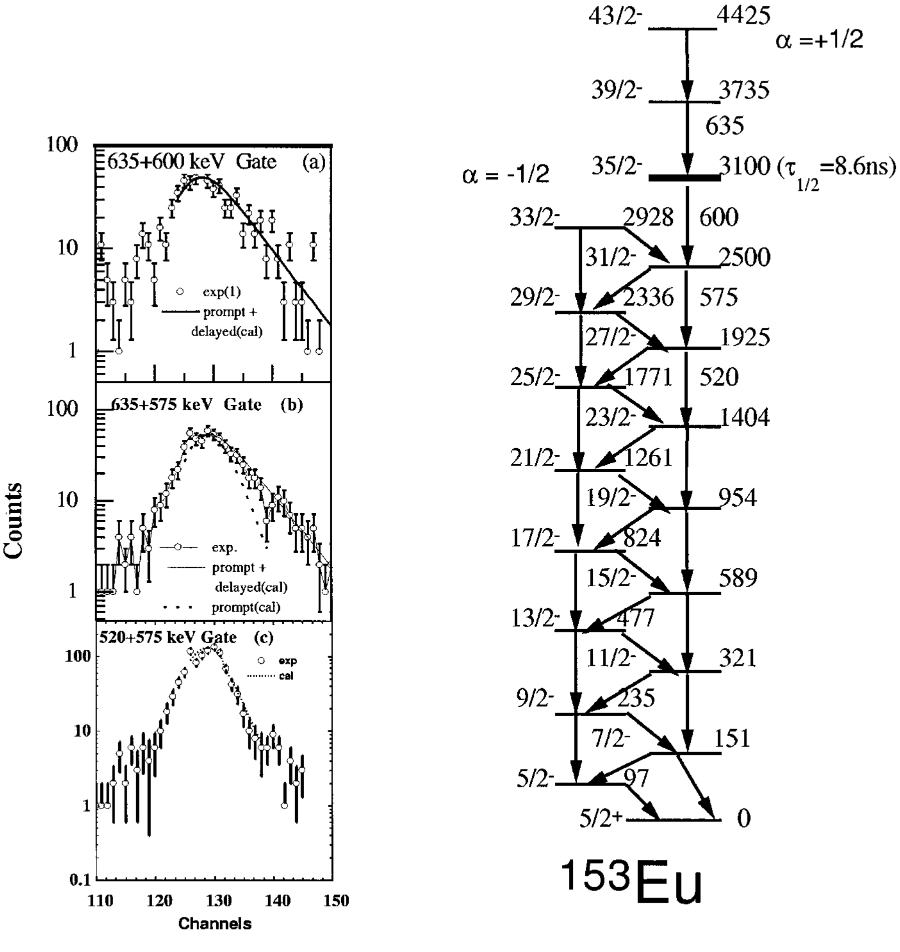

Fig. 3. Projected γ-gated time spectra are shown, **a** 635 keV feeding and 600 keV decaying from the 3100 keV level are selected as gates, the time spectrum shows both prompt and delayed components; **b** similar feature when gated with 635 and 575 keV decaying from the 2500 keV level. The *solid lines* in both **a** and **b** curves show the fitting with the RESFIT program (see the text). The *dashed curve* fitted with the prompt peak shown in **c** is normalised to the data of **b**. Prompt time spectrum gated with 575 and 520 keV γ-rays feeding the 1925 keV level and decaying from the same state respectively is displayed in **c**. The *dotted curve* in **c** is the fit by the above mentioned code. In the right side, a partial level scheme shows the negative parity band indicating the isomeric level with bold thick line

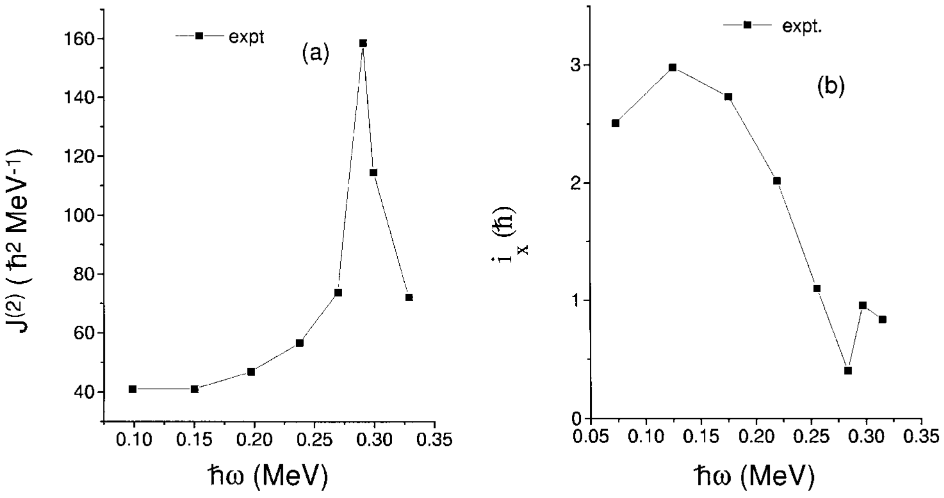

Fig. 4. **a** plot of variation of $\mathcal{J}^{(\in)}$ with rotational frequency showing the band crossing at $\hbar\omega$ ~0.30 MeV. **b** displays the change of single particle alignment with increase of rotational energy. At $\hbar\omega$ ~0.30 MeV the alignment of the angular momentum of the proton in $h_{11/2}$ orbital is minimum due to mixing with the momenta of protons occupying the low-j orbitals. Above this frequency, the angular momentum gain is possibly due to the neutron pair breaking. Both these curves are for signature $\alpha = +1/2$

the same level. In this band these ratios for the $23/2^-$ to $31/2^-$ spin range varies from 0.05 to 0.2 whereas for spin $35/2^-$ the ratio is 0.9 which indicates that there is a sudden change in intensity in the E2 transition with respect to M1 transition. Corresponding to these spins, the dynamical moment of inertia $\mathcal{J}^{(2)}(\Delta E_\gamma/4)$ shows a band crossing for the signature α=+1/2 which is displayed in Fig. 4a.

The gain of angular momentum $i_x(\omega)$ has been estimated from the relation

$$i_x(\omega) = I_x(\omega) - I_{xg}(\omega)$$

where $I_x(\omega)$ is the total angular momentum gain and is obtained from the exprimental result and I_{xg} $(=\omega\mathcal{J}_0 + \omega^3\mathcal{J}_1)$, the reference angular momentum has been estimated from the ground state rotational bands of neighbouring even-even ^{152}Sm and ^{154}Gd nuclei. The values of the inertial parameters obtained are $\mathcal{J}_0$=23.3 $\hbar^2$/MeV and $\mathcal{J}_1$= 352.7 $\hbar^4$/MeV^3 for ^{152}Sm and $\mathcal{J}_0$= 23.1 $\hbar^2$/MeV and $\mathcal{J}_1$=332.9 $\hbar^4$/MeV^3 for ^{154}Gd. The behaviour of $i_x(\omega)$ in Fig.4b for the negative parity band could be explained in the following way: the negative parity band is built on $\pi h_{11/2}$ orbital and this orbital carries a large component of the angular momentum. Initially, with rotation the angular momentum alignment for the negative parity band increases and reaches a maximum value at the rotational frequency $\hbar\omega$~0.14 MeV (Fig. 4b). Above this frequency there is a quenching of $i_x(\omega)$ due to the mixing of angular momenta of high-j intruder state with the low-j normal parity states. Such quenching is interpreted by Nazarewicz and Tabor [14] to be a manifestation of increase of collectivity and hence change of shape due to the development of odd multipole deformations. In ^{153}Eu, with increasing rotational energy a possible mixing between the $\pi h_{11/2}$ unique parity orbital and the close-lying normal parity orbitals, $d_{5/2}$ and $g_{7/2}$ gives rise to a fragmentation of the total alignment strength thereby bringing down the single particle alignment $i_x(\omega)$. With further excitation a promotion of a proton in the next higher orbital is improbable due to the Pauli blocking. On the other hand, the $\nu f_{7/2}$ and $\nu i_{13/2}$ orbitals are near the neutron Fermi surface. The gain in angular momentum above $\hbar\omega$~0.30 MeV is likely due to promotion of a neutron pair lying in $\nu f_{7/2}$ to the $\nu i_{13/2}$ orbital which leads to a configuration change.

We may conclude by mentioning that the observation of the 8.6(1.3)ns isomer at J^π=$35/2^-$ in the nucleus ^{153}Eu indicates the possibility of a configuration change at this spin value.

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