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Short Note

High-spin states in odd-odd ^{168}Lu

S.K. Katoch[1], S.L. Gupta[1], S.C. Pancholi[1], D. Mehta[1], S. Malik[1], G. Shanker[1], L. Chaturvedi[2], R.K. Bhowmik[3]

[1] Department of Physics and Astrophysics, University of Delhi, Delhi-100 007, India
[2] Department of Physics, Banaras Hindu University, Varanasi-221 005, India
[3] Nuclear Science Centre, Aruna Asaf Ali Marg, New Delhi-110 067, India

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Abstract. High-spin states in the odd-odd ^{168}Lu nucleus, populated in the ^{154}Sm(^{19}F,5n) reaction at a beam energy of 96 MeV, were investigated using in-beam γ-ray spectroscopy techniques. The BC neutron crossing in the yrast band, based on $\pi g_{7/2}[404]7/2^+ \otimes \nu i_{13/2}[642]5/2^+$ configuration, occurs at $\hbar\omega$=0.31 MeV. The two side bands, based on $\pi h_{11/2}[514]9/2^- \otimes \nu i_{13/2}[642]5/2^+$ and $\pi h_{9/2}[541]1/2^- \otimes \nu i_{13/2}[642]5/2^+$ configurations, show anomalous signature-splitting and signature-inversion in the first one, to occur at $\hbar\omega$=0.24 MeV. A moderately delayed BC-crossing is anticipated in the second one.

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The spectroscopic studies of odd-odd nuclei in the rare-earth region have gained momentum during the recent years. These investigations have revealed interesting features like anomalous signature-splitting and signature-inversion in the high K $\pi h_{11/2} \otimes \nu i_{13/2}$ bands [1] and disappearance of the blocking effect of an odd-neutron in the $\pi h_{11/2} \otimes \nu h_{9/2}$ bands [2]. We have studied high-spin states in the odd-odd ^{168}Lu nucleus to improve the understanding of the nuclear properties associated with the odd-odd nuclei focussing on the following experimentally observable quantities : (i) alignment and band crossing frequencies, (ii) energy-signature splittings, and (iii) transition rates. Detailed results of this spectroscopic study will be presented in a coming article. During the course of the present work, a short note [3] reporting two signature-split bands in ^{168}Lu appeared in the literature. The present work provides more extensive spectroscopic information and covers a higher spin-range.

High-spin states in the odd-odd ^{168}Lu nucleus were populated via the reaction ^{154}Sm(^{19}F,5n) ^{168}Lu at a beam energy of 96 MeV. The beam was provided by the 15 MV Pelletron accelerator of the Nuclear Science Centre (NSC), New Delhi. An enriched and self-supporting ^{154}Sm target of thickness 2.0 mg/cm^2 was used. The spectroscopic measurements were done using the gamma detector array (GDA) [1,2] consisting of 7 Compton-suppressed Ge detectors and a 14-elements bismuth germanate (BGO) multiplicity filter. The Ge detectors were positioned at 45^o, 99^o and 153^o to the beam direction. A total of 100 million two-fold events were collected. In the off-line sorting of the data, γ-ray spectra from the Ge detectors were gain matched to 0.5 keV/channel and a 4K x 4K E_γ-E_γ matrix was generated with the requirement of more than one BGO multiplicity detector firing. The γ-ray coincidence relationships were established by setting gates on the photopeaks of individual transitions assigned to the ^{168}Lu nucleus and projecting the coincident spectra. The assignment of γ-rays to ^{168}Lu was based on their coincidences with Lu K X-rays and previous knowledge of the level schemes of the neighbouring, ^{167}Lu [4] and ^{169}Lu [5], isotopes. The multipolarities to the gamma transitions were assigned on the basis of measured DCO [$=I_\gamma(153^o)/I_\gamma(99^o)$] ratios extracted from the coincidence data. The DCO ratios were found close to 1 and 0.6 for E2 and M1 transitions, respectively.

The level scheme of ^{168}Lu established from the present work is shown in Fig. 1. It consists of three signature-split bands (labeled band-A, band-B and band-C). The placement of transitions in the bands is based upon their intensities, energy sums and coincidence relationships. The relative placement of these bands is arbitrary as neither interband transitions nor transitions from these bands to ground state could be confirmed. The bands B and C at lower levels with I≤10 are found to feed into levels of band A with I≤9. Due to the hanging nature of the level scheme, the spin assignments cannot be made by usual spectroscopic methods. For the levels in band A and band C, the spins have been suggested on the basis of the available

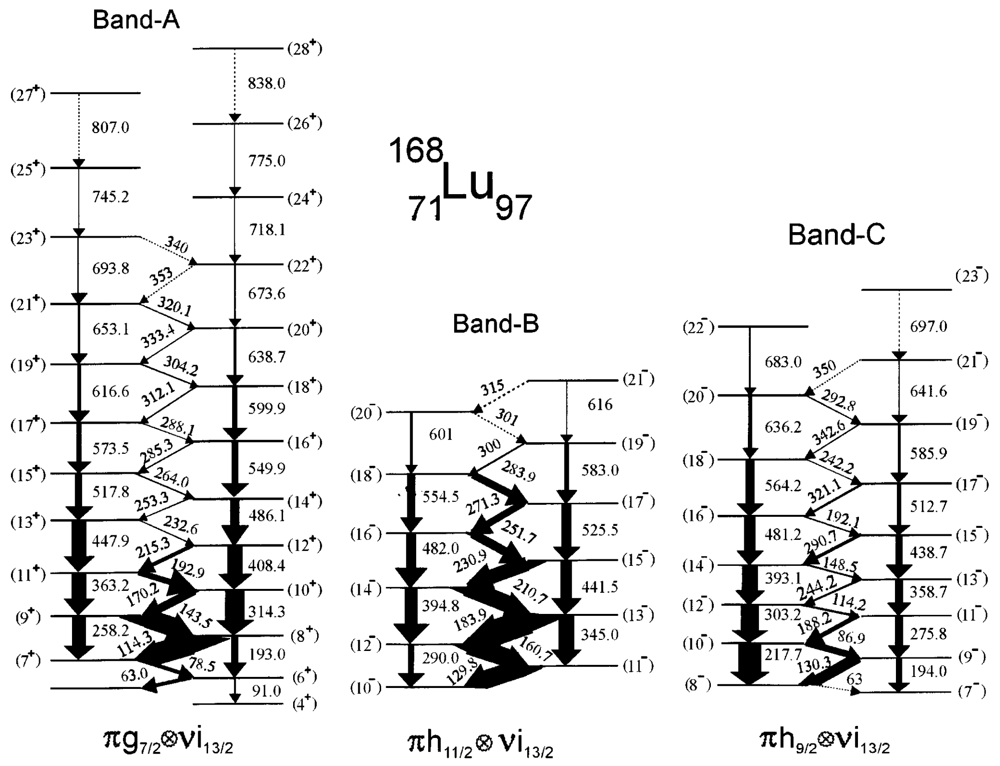

Fig. 1. The proposed level scheme of the ^{168}Lu nucleus

spin vs level energy systematics of the similar configuration bands in the ^{166}Tm [6] and ^{162,164}Tm and ^{174}Ta nuclei [7], respectively, where a firm spin assignments have been achieved. The present spins for levels in band A differ by $1\hbar$ from those reported by Ha et al. [3]. The spins for the levels in band B have been suggested with the help of level energy systematics of the $\pi h_{11/2} \otimes \nu i_{13/2}$ bands in the odd-odd $^{156-162}$Ho, $^{158-166}$Tm and $^{160-166}$Lu nuclei [1]. The suggested spins are also supported by the Cranked-shell model arguments and the recipe proposed by Drissi et al. [8].

The proton and the neutron Nilsson configurations to bands A, B and C (Fig. 1) is suggested with the help of experimentally deduced B(M1)/B(E2) raios, dynamic moment of inertia ($J^{(2)}$), band crossing frequencies and the principle of coupling alignments of the quasiproton and quasineutron bands in the neighbouring odd-A nuclei. Bands A, B and C are proposed to be built on the $\pi g_{7/2}[404]7/2^+ \otimes \nu i_{13/2}[642]5/2^+$, $\pi h_{11/2}[514]9/2^- \otimes \nu i_{13/2}[642]5/2^+$ and $\pi h_{9/2}[541]1/2^- \otimes \nu i_{13/2}[642]5/2^+$ Nilsson configurations, respectively. The sum of aligned angular momenta of the participating odd-neutron and odd-proton, deduced from the neighbouring ^{167}Lu [4] and ^{167}Yb [9] nuclei, respectively, is found to match with the aligned angular momenta for bands A, B and C for the suggested level-spins and configurations.

Band A, being the most populated structure in this reaction, is most likely the yrast band. The crossing in this band occurs at $\hbar\omega$=0.31 MeV (Fig. 2) with an alignment gain Δi=4.5$\hbar$, which is very close to the BC neutron crossing observed at $\hbar\omega$=0.32 MeV with Δi=4.3$\hbar$ for the $i_{13/2}$ neutron pair in ^{167}Yb isotone [9]. The AB neutron crossing which occurs at $\hbar\omega = 0.27$ MeV with $\Delta i = 9\hbar$ is certainly absent in this case. This indicates that the neutron partner in the band A is from the $i_{13/2}$ orbital. Further, the $i_{13/2}[642]5/2^+$ configuration is assigned to the yrast band in the neighbouring odd-N ^{167}Yb [9] and ^{169}Hf [10] nuclei, hence is most likely to be involved in

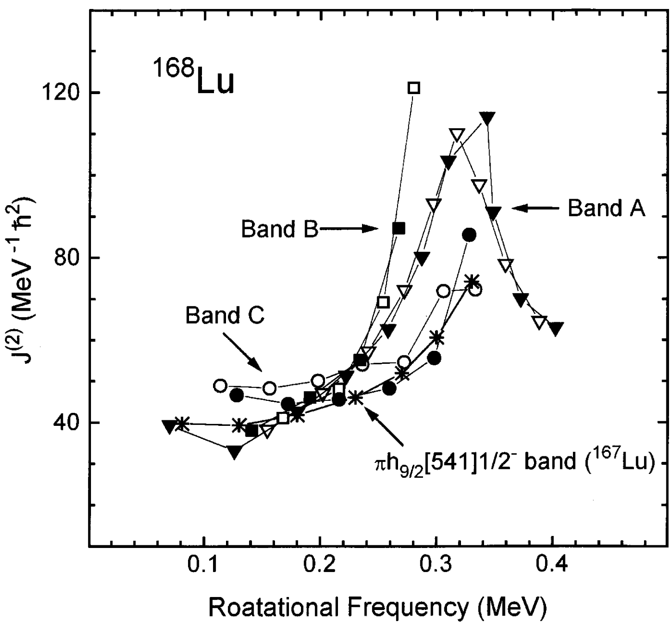

Fig. 2. Dynamic moment of inertia ($J^{(2)}$) as a function of rotational frequency

the configuration of band A. This band exhibits small signature-splitting ($\Delta e' \leq 15keV$) above $\hbar\omega$ =0.20 MeV with the α=1 sequence (odd spins) becoming experimentally favoured signature, whereas, the α=0 sequence was expected to be the favoured one. The average experimental B(M1)/B(E2) value 0.2 μ_N^2/e^2b^2 for this band below the BC bandcrossing agree with the values, ranging 0.10-0.25 μ_N^2/e^2b^2, as expected for the proposed configuration from the geometrical model of Dönau and Frauendorf [1]. It is interesting to note that the yrast band in ^{168}Lu is not built on the $\pi h_{11/2} \otimes \nu i_{13/2}$ configuration as observed in the odd-odd $^{160-166}$Lu isotopes and a few other rare-earth odd-odd nuclei [1].

Band B exhibits anomalous signature-splitting and the signature-inversion in this band occurs at $\hbar\omega$=0.24 MeV. This value of inversion frequency fits well in the systematics of $\pi h_{11/2} \otimes \nu i_{13/2}$ bands in the odd-odd nuclei in this mass-region [1]. The inversion frequency is found to be nearly constant for a series of nuclei with a given N-Z value. The BC bandcrossing region in band B is just approached (Fig. 2). The dynamic moment of inertia for band C is larger and remain constant for a wider range of rotational frequency. This behaviour is similar to $\pi h_{9/2}[541]1/2^-$ band in ^{167}Lu (Fig. 2). Hence, $\pi h_{9/2}[541]1/2^-$ is the most likely proton partner in the configuration of this band. The crossing in the band is anticipated to occur at $\hbar\omega \geq 0.34$ MeV and is interpreted as BC neutron crossing. Band C also shows anomalous signature-splitting ($\Delta e' \leq 60keV$). No signature-inversion is seen in this band. Anomalous signature splitting in the $\pi h_{9/2} \otimes \nu i_{13/2}$ bands of rare-earth odd-odd nuclei has been interpreted as being the result of a residual proton-neutron interaction [7]. The moderate delay in the BC neutron crossing may also be associated with the same residual proton-neutron interaction. The average experimental B(M1)/B(E2) values 0.9 and 0.1 μ_N^2/e^2b^2 for band B and band C, respectively, are also in general agreement with the values expected from the geometrical model of Dönau and Frauendorf [1] for the suggested configurations.

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