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Short note

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

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Abstract. High-spin states of odd-odd ^{168}Lu were observed up to $18\hbar$ for the first time using the ^{159}Tb(^{13}C, 4nγ)^{168}Lu reaction at $E_{13C} = 58.5$ MeV. $\gamma - \gamma$ coincidence, E_γ singles, excitation function, and the DCO ratios were measured. Two rotational bands with signature splitting were populated, among which the lower-energy band is identified as $\pi 7/2^+[404] \otimes \nu 5/2^+[642]$ in view of alignment and energy systematics.

PACS. 23.20.Lv Gamma transitions and level energies – 27.70.+q $150 \le A \le 189$

High-spin states of odd-odd nuclei near $A = 150$ and 190 have shown several intriguing phenomena such as an anomalous(delayed) bandcrossing [1,2], the identical band problem (e.g., $^{173-175}$Lu [3] and $^{171-175}$Ta [4]), and signature inversion [5]. In lutetium isotopes, previous high-spin studies were reported on ^{160}Lu [6], ^{162}Lu [7], ^{164}Lu [1,2], and ^{166}Lu [8]. However, no such studies have been done on ^{168}Lu to date. The known states are merely low-lying levels obtained by β-decay works [9,10].

In the present work, high-spin states of odd-odd ^{168}Lu have been observed up to $18\hbar$ or higher for the first time using the ^{159}Tb(^{13}C, 4nγ)^{168}Lu reaction at a beam energy of 58.5 MeV. The ^{13}C beam was provided by the KUTL tandem accelerator at Kyushu University. The target of ^{159}Tb was a self-supporting foil of 8.5 mg/cm^2 in thickness. In order to identify γ rays belonging to lutetium isotopes, the X-γ coincidence employing a low energy photon spectrometer (LEPS) was performed at two different beam energies of 55.0 and 58.5 MeV. Figure 1 shows the spectra gated by the 54.1-keV K X-ray of lutetium for the two beam energies. The population of ^{169}Lu whose γ rays are well known is seen to be preferred at the lower energy. The remaining γ rays, as shown in Fig. 1a, are likely to be candidate γ rays belonging to ^{168}Lu.

After having identified γ rays belonging to lutetium isotopes - ^{168}Lu and ^{169}Lu being predominantly populated, we performed the singles measurements for the excitation function at three different beam energies of 50.0, 55.0, and 58.5 MeV in order to distinguish γ rays of ^{168}Lu from those of ^{169}Lu. The latter, corresponding to the 3n channel, is expected to be populated at a lower beam energy. The population of of ^{168}Lu is found to be most preferred at 58.5 MeV, and yields of ^{168}Lu relative to ^{169}Lu as a function of beam energy prove to be consistent with the CASCADE result [11]. The γ-γ coincidence measurement was performed at the beam energy of 58.5

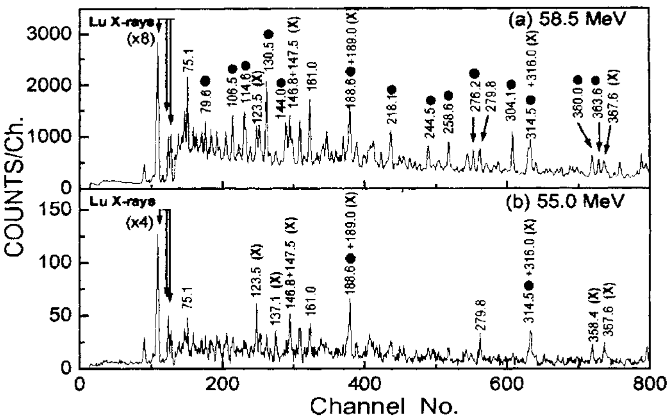

Fig. 1. Coincidence spectra gated by the 54.1-keV K X-ray of Lu taken at two different beam energies of **a** 58.5 and **b** 55.0 MeV. *Solid circles* represent transitions belonging to ^{168}Lu and (X) to ^{169}Lu, respectively

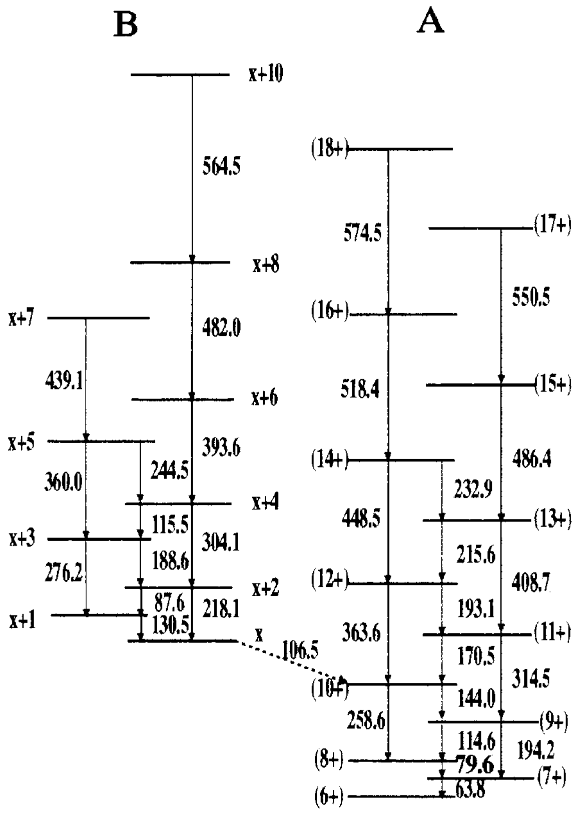

Fig. 2. Level scheme of ^{168}Lu

MeV. We used three high-purity germanium (HPGe) detectors two of which were covered with bismuth germanate anti-Compton shield (BGO-ACS) and one LEPS. The two HPGe detectors with BGO-ACS were set at 90^o, 55^o, one HPGe without BGO-ACS at 65^o, and the LEPS at 125^o, with respect to the beam direction. A total of 26 million coincidence events were collected during the experiment. Multipolarities of γ rays were determined from the DCO (Directional Correlation from Oriented states) ratio, defined as $I_\gamma(55^o$, gated by $90^o)/I_\gamma(90^o$, gated by $55^o)$ using an adjacent gate of stretched $E2$ transition. The DCO ratios turned out to be ≈ 1 for $\Delta I = 2$ and ≈ 0.6 for $\Delta I = 1$ transitions, respectively. Activity measurements were also performed by turning the beam off to identify γ rays of β-decay activities.

The level scheme consisting of two rotational bands is shown in Fig. 2. The bandhead spin and parity of band A is found to be 6^+ by using the Drissi's recipe [12] and the energy systematics of neighboring odd-odd nuclei (^{166}Lu [8], ^{166}Tm [13], ^{162,164}Tm [14]). The configuration of the band A is proposed as $\pi 7/2^+[404] \otimes \nu 5/2^+[642]$. Another rotational band B with weaker population is linked with the yrast band A via the 106.5 keV transition. Although this transition appears to be of dipole character from the DCO ratio, its intensity is too weak to make a firm assignment of spins for the members of band B.

The calculation using the Harris parameters of $\mathcal{J}_0 = 29\,\hbar^2/\mathrm{MeV}$ and $\mathcal{J}_1 = 125\,\hbar^4/\mathrm{MeV}^3$ showed that the alignment for band A monotonically increases from $4\hbar$ to $6\hbar$ up to $\hbar\omega \approx 0.28$ MeV. This could be probably due to the

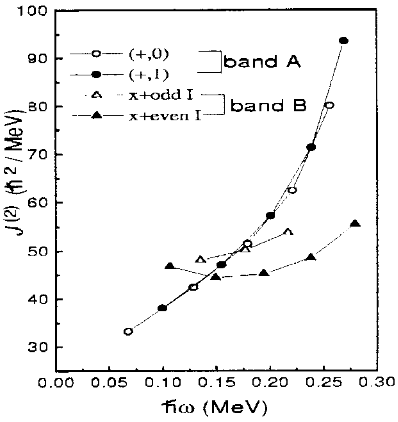

Fig. 3. Dynamic moments of inertia of the band A and B in ^{168}Lu

progressive proton alignment when the alignment is compared to the neighboring odd-A nuclei such as ^{165}Yb and ^{167}Lu [15,16]. This supports the general tendency that the neutron alignment remains rather constant before bandcrossing in this mass region [12]. The alignment additivity rule applied to these odd-A nuclei yielded $\approx 4.9\hbar$ [15,16], being close to the mean value of the alignment for band A. The dynamic moments of inertia, shown in Fig. 3, increase with increasing rotational frequency with a steeper slope for band A, which is another evidence for the progressive proton alignment. We also observed a sign of the existence of two more rotational bands with a limited number of transitions. A further experiment using heavier beams is being planned in order to draw a richer level scheme and also address the intriguing problems in this odd-odd ^{168}Lu nucleus.

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