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Short note

Observation of intermediate bands feeding the positive-parity yrast band in ^{155}Gd

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Abstract. High-spin states of ^{155}Gd were populated by using the ^{154}Sm(α,3nγ)^{155}Gd reaction at E_α = 33 MeV. $\gamma - \gamma$ coincidence, E_γ singles, excitation function, and the DCO ratios were measured. we have identified three intermediate bands with $\Delta I = 2$ feeding the positive yrast band. The bands are interpreted as such candidate bands that are mixed with the negative-parity ground state band. This observation can provide a plausible explanation for unusually large population of the positive-parity yrast band observed in a recent Coulomb excitation.

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

A recent Coulomb excitation (COULEX) result on ^{155}Gd, reported by Kidera et al. [1], showed an interesting experimental observation that the positive-parity rotational band $3/2^+$[651] was populated in strength comparable to the negative-parity ground state band $3/2^-$[521]. This unusually large population is contradictory to the customary notion that COULEX populates a band via electric quadrupole (*E2*) excitation for which parity of the preferentially populated band is the same as that of the ground state band. A direct *E1* or *E3* excitation would require a large enhancement of transition strength *B(E1)* or *B(E3)* by at least one order of magnitude even if the recommended upper limit values in this mass region were used for transition strength [2]. In a more recent COULEX experiment done by Stuchbery et al. [3], it was suggested that such large population reported in [1] could be attributed to an inelastic scattering or Coulomb-nuclear interference and the octupole (*E3*) correlation should play a major role of populating the postive-parity band. However, evidence for such a direct excitation is still lacking in experimental observation.

An alternative explanation for the COULEX result can be made on the basis of indirect excitation through intermediate states that are mixed with the states belonging to the ground state band. Such mixing would generate numerous intermediate states and their side-feeding transitions to the states of the positive-parity band could lead to their large population strength in all. In the present work, we searched for the intermediate states that are mixed with the $3/2^-$[521] ground state band members and feed the levels belonging to the $3/2^+$[651] band. Since these intermediate bands are likely to be non-yrast, we made use of the (α,xn) reaction to take advantage of its non-selective population in contrast with a heavy-ion induced reaction. The adoption of the (α,xn) reaction is particularly sensitive to identifying side-feeding paths to the the $3/2^+$[651] band because this band is yrast. The unobserved intermediate states in previous COULEX experiments could

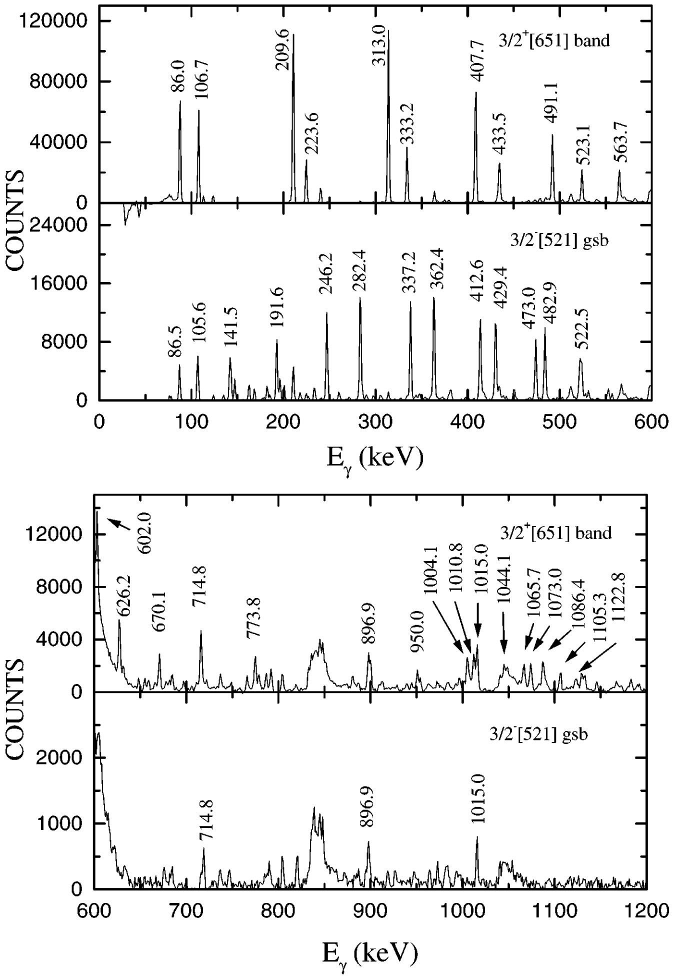

Fig. 1. Sum gated spectra obtained by several strong transitions belonging to the $3/2^+[651]$ yrast and $3/2^-[521]$ ground state bands. Note that the intensities of major gamma rays for the $3/2^+[651]$ yrast band are shown seven or eight times higher than those for the $3/2^-[521]$ ground state band in the region of $0 \leq E_\gamma \leq 600$ keV (top panel). In the bottom panel ($600 \leq E_\gamma \leq 1200$ keV) drawn in a different vertical scale, there are many gamma rays in coincidence with the $3/2^+[651]$ yrast band members

be identified in our reaction inherently possessing a capability that "amplifies" the side-feeding transitions to the yrast band in comparison with COULEX. In a favorable case, such intermediate states will form rotational bands if their population strengths are not fragmented.

We performed the ^{154}Sm(α,3nγ)^{155}Gd experiment using the enriched self-supporting ^{154}Sm target with areal density of 1.5 mg/cm^2. The excitation function measurement was done at beam energies of 28 to 36 MeV in steps of 1.5 MeV using the AVF cyclotron at Korea Cancer Center Hospital. The yield of ^{155}Gd turned out to be optimum at the beam energy of 33 MeV. The γ-γ coincidence experiment was performed at this beam energy using the SF cyclotron at Center for Nuclear Study, University of Tokyo. Gamma rays were detected by five anti-Compton high-purity germanium detectors with BGO shield in transverse geometry, placed at the angles of 30°, 37°, 90°, 143°, and 270° with respect to the beam axis. The time-to-digital converter (TDC) range was set at 500 ns and total 53 million coincidence events were collected. The coincidence data were analyzed by the RADWARE code and the spin-parity assignment was made through extracting the directional correlation for oriented nuclei (DCO) ratios. In the present work, we found more than 10 new gamma rays belonging to the previously known $3/2^-[521]$ ground state band and two side bands $3/2^+[651]$, $11/2^-[505]$. In addition, nearly 30 new gamma rays were found to be in coincidence with transitions belonging to the $3/2^+[651]$ band. These new gamma rays are ranged from 500 keV to 1.2 MeV in energy with the majority of them being preferentially linked with the $3/2^+[651]$ yrast band as shown in Fig. 1.

A partial level scheme for the yrast $3/2^+[651]$ band and three newly found intermediate rotational bands A, B and C is shown in Fig. 2. The yrast $3/2^+[651]$ band exhibits a highly staggered behavior with upside-down level sequence. Two previous reports [4,5] suggest that this feature is attributed to the $\Delta K = 1$ Coriolis mixing with other side bands $5/2^+[642]$ and $1/2^+[660]$ pertaining to the $i_{13/2}$ orbital near the Fermi level in ^{155}Gd. Our level scheme established up $41/2^+$ for the yrast band is in good agreement with a previous report obtained by the heavy-ion fusion evaporation reaction [6].

For the three newly found intermediate bands A, B and C, the eleven intraband transitions turned out to be $\Delta I = 2$ from the DCO ratios, forming rotational bands. The other thirteen transitions all side-feed the levels with signature $\alpha = +1/2$ in the yrast $3/2^+[651]$ band while no transition to the $3/2^-[521]$ ground state band was observed. In addition, there were also observed several other transitions, not placed in the level scheme, linked with the yrast band. The spectra gated by four intraband transitions belonging to band A are shown in Fig. 3. The efficiency-corrected intensities for these intraband transitions are a few percents of the intensity for the strongest 209.6 keV transition in the yrast band. The spin-parity assignment for the three bands A, B and C still remains unresolved in the present work due to large uncertainties of the DCO ratios for those high-energy side-feeding transitions to the yrast $3/2^+[651]$ band. The number of observed linking transitions in the present work amounts to nearly 20 and can lead to considerably large population of the yrast band. There must be numerous undetected linking transitions because the sum of the intensities for the observed linking transitions makes only about 30 % of the 209.6 keV intensity.

Assuming that these three intermediate bands A, B and C are mixed with the ground state band, i.e., of the same negative-parity states, one can explain why transitions deexciting these bands are linked with the positive-parity yrast band only, not with the ground state band. The branching ratios $T(E1)/T(E2)$ of the intraband ($E2$) transitions in bands A, B and C to the interband ($E1$) transitions between bands A, B and C and the positive-

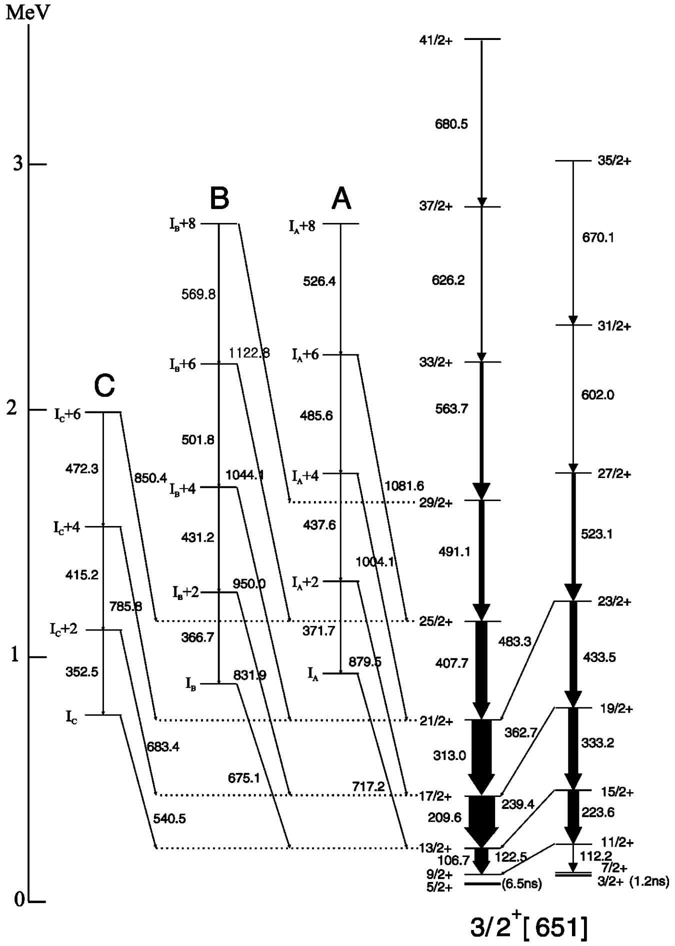

Fig. 2. A partial level scheme of ^{155}Gd

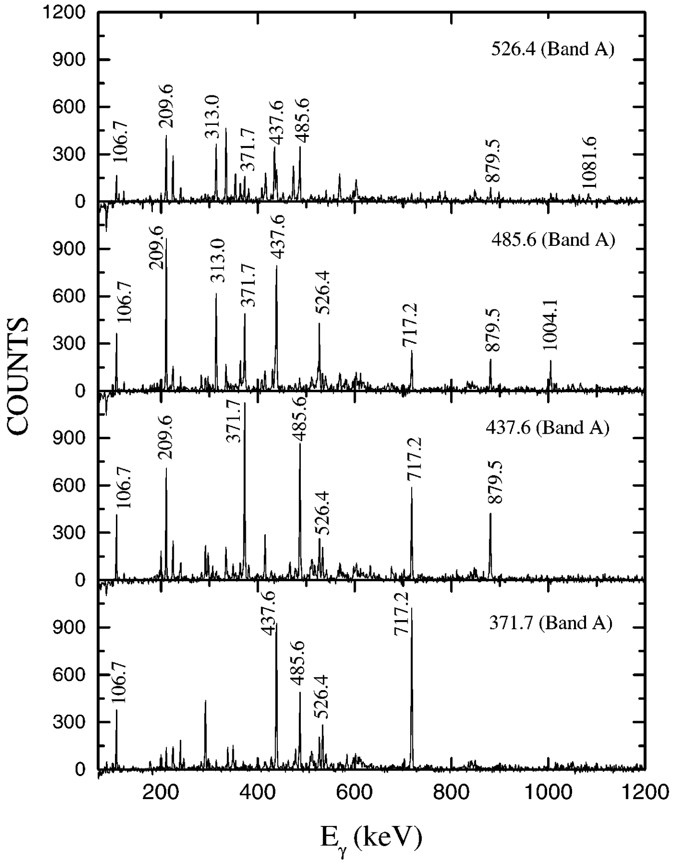

Fig. 3. Spectra gated by four intraband transitions of an intermediate band A

parity yrast band, were obtained from the efficiency-corrected intensity ratios for the relevant transitions. In a well deformed nucleus, the $B(E2)$ values for intraband transitions are somewhat equally the same regardless of intrinsic structure. Using the measured $B(E2)$ values for the intraband transitions in the ground state band [7], the $B(E2)$ values for intraband transitions in bands A, B and C were taken between 200 and 300 Weisskopf units (W.u.). The extracted $B(E1)$ values are ranged $2 \sim 9 \times 10^{-5}$ W.u., $3 \sim 18 \times 10^{-5}$ W.u., $9 \sim 22 \times 10^{-5}$ W.u., respectively for the relevant transitions deexciting bands A, B and C. These values are typical for interband $E1$ transitions in low-lying transitions in many well deformed nuclei in this mass region. Having extracted the $B(E1)$ values for interband transitions between bands A, B and C and the positive-parity yrast band, we estimated the branching ratios of the interband ($E2$) transitions (between bands A, B and C and the ground state band) to the interband ($E1$) transtions (between bands A, B and C and the positive-parity yrast band). For this estimation, transition energies for the unobserved interband ($E2$) transitions (between bands A, B and C and the ground state band) were used by taking difference of level energies for the relevant states. The $B(E2)$ values for interband transitions were taken 3 W.u. in average as those for the β and γ bands in the neighboring ^{154}Gd were ranged $2 \sim 5$ and $2.4 \sim 4.4$ W.u., respectively [8]. The transition rates $T(E1 : \mathrm{A,B,C} \rightarrow 3/2^+[651])$, for interband transitions between bands A, B and C and the positive-parity yrast band, were ranged $4 \sim 35 \times 10^{10}$ sec^{-1}, $10 \sim 80 \times 10^{10}$ sec^{-1} and $8 \sim 21 \times 10^{10}$ sec^{-1}, respectively for bands A, B and C. The transition rates $T(E2 : \mathrm{A,B,C} \rightarrow 3/2^-[521])$, for interband transitions between bands A, B and C and the ground state band, were ranged $2.3 \sim 3.4 \times 10^{10}$ sec^{-1}, $1.7 \sim 2.8 \times 10^{10}$ sec^{-1} and $0.7 \sim 0.8 \times 10^{10}$ sec^{-1}, respectively for bands A, B and C. The overall branching ratios $T(E2 : \mathrm{A,B,C} \rightarrow 3/2^-[521])/T(E1 : \mathrm{A,B,C} \rightarrow 3/2^+[651])$ turned out to be less than 0.1, which is close to the detection limit in the present work. Therefore, no interband transitions between the three intermediate bands and the ground state band would have been observed.

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