IDENTIFICATION OF 38 keV γ TRANSITION IN ^{132}La AMIDST X RAYS

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We identified and confirmed a low-energy (38 keV) γ transition in ^{132}La by comparing the intensity ratio of La X rays. The state with spin 7^+, known as the multiplet of $\pi h_{11/2} \otimes \nu h_{11/2}$, has further been investigated for its nature as isomeric. A negative parity band was closely observed in comparison with the neighboring isotones $^{130}_{55}$Cs$_{75}$ and $^{134}_{59}$Pr$_{75}$, and for the first time the configuration $\pi d_{5/2} \otimes \nu h_{11/2}$ was assigned.

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1. Introduction

Nuclear energy states possess rich information about the nuclear structure. In order to understand the structure using theoretical models, we need the confirmed spin and parity assignment to states, in particular, near the bandhead. However, we often face difficulty in obtaining accurate and reliable data on the decay properties. The reason could be the presence of isomeric states or low-energy gamma transitions which are attenuated and below the observation sensitivity thresholds for typical experiments. Moreover, if the gamma energy is very near to the X rays emitted by the same nucleus, it becomes practically impossible to isolate the gamma.

In the previous studies of ^{132}La [1, 2], a new 350 keV transition played a crucial role in assigning the bandhead spin 8^+ (Fig. 1) with configuration $\pi h_{11/2} \otimes \nu h_{11/2}$. In a parallel decay path to 350 keV γ ray, a 38 keV transition was placed indirectly to satisfy the coincidence condition with all the neighboring transitions. However, there was no experimental evidence shown for the presence of 38 keV gamma transition in ^{132}La by either our work [1] or by Timar *et al.* [2]. In fact, we always observed a pair of peaks at 33 and 38 keV corresponding to the X rays of La in all gated coincidence spectra; the ratio between the two peaks could enable us to isolate the gamma of 38 keV amidst the X-ray peak. Besides, we have now examined the nature of the bandhead 8^+ (Fig. 1) with configuration $\pi h_{11/2} \otimes \nu h_{11/2}$ as being isomeric. We have also proposed $\pi d_{5/2} \otimes \nu h_{11/2}$ configuration to a known band — very similar and interlinked to $\pi g_{7/2} \otimes \nu h_{11/2}$ band [1, 2] — by pointing out the similarities with neighboring isotones $^{130}_{55}$Cs$_{75}$, $^{132}_{57}$La$_{75}$ and $^{134}_{59}$Pr$_{75}$. In essence, we report here an addendum to our previous results [1], obtained by further analyzing and investigating the same experimental data.

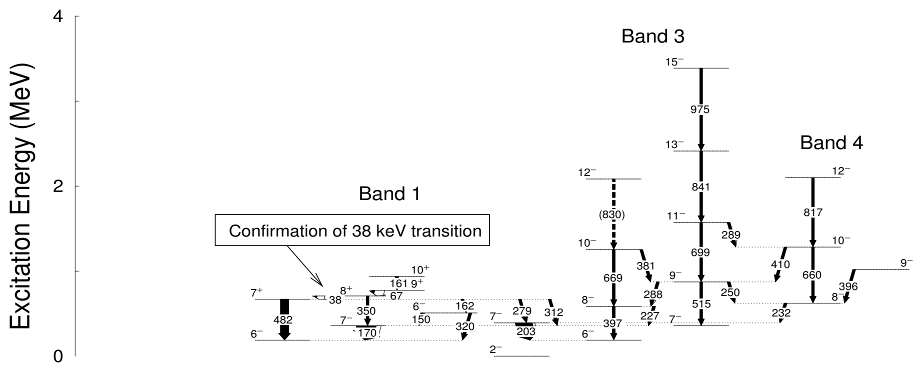

Fig. 1. Partial level scheme of ^{132}La [1]: Band 1 for $\pi h_{11/2} \otimes \nu h_{11/2}$, Band 3 for $\pi g_{7/2} \otimes \nu h_{11/2}$ and Band 4 for $\pi d_{5/2} \otimes \nu h_{11/2}$ (present proposition).

2. Experiments and data analysis

We studied ^{132}La using ^{14,15}N beams (4–6 MeV/nucleon) on ^{122}Sn target via fusion–evaporation reactions. We performed experiments at the heavy-ion Pelletron accelerator facilities at two places — the Inter-University Accelerator Center (formally known as the Nuclear Science Center, New Delhi, India) and the Tata Institute of Fundamental Research (Mumbai, India). The multi-detector arrays consisted of 8–12 Compton suppressed coaxial HPGe detectors — placed in the forward, backward and near perpendicular to the beam direction — and a 14-element BGO multiplicity filter. For the construction of level scheme, we utilized a ^{122}Sn foil (1.2 mg/cm^2) on a thick lead backing; while, for the lifetime measurement, we utilized ^{122}Sn (0.5 mg/cm^2) rolled on to a gold foil (2 mg/cm^2) and stretched. We measured the lifetimes using the technique of recoil distance method. The double-coincidence data were collected in list mode. The initial steps of data analysis — the energy calibration, efficiency measurement, construction of symmetric and asymmetric E_γ–E_γ matrices — were carried out following the standard procedures. Further details on the experiments and data analyses were presented in our earlier works [1, 3].

3. $\pi h_{11/2} \otimes \nu h_{11/2}$ band

3.1. Presence of 38 keV γ transition

To ascertain the presence of 38 keV γ transition, we examined the intensity ratio ($I_\gamma(33)/I_\gamma(38)$) of two La X rays of energy 33 keV and 38 keV. This ratio was found to be around 1:0.25 in the absence of 38 keV γ ray. Figure 2 (b) and (c) presents illustrative examples of La X rays in coincidence with the gamma transitions of energy 350 keV and 230 keV, respectively, belonging to ^{132}La. The mentioned intensity ratio was constant not only for the X-ray pair of ^{132}La but also for the other observed lanthanum isotope ^{133}La, as shown in Fig. 2 (d) corresponding to the gate on 477 keV γ ray. However, when the 38 keV peak contained both the X ray and γ ray, we

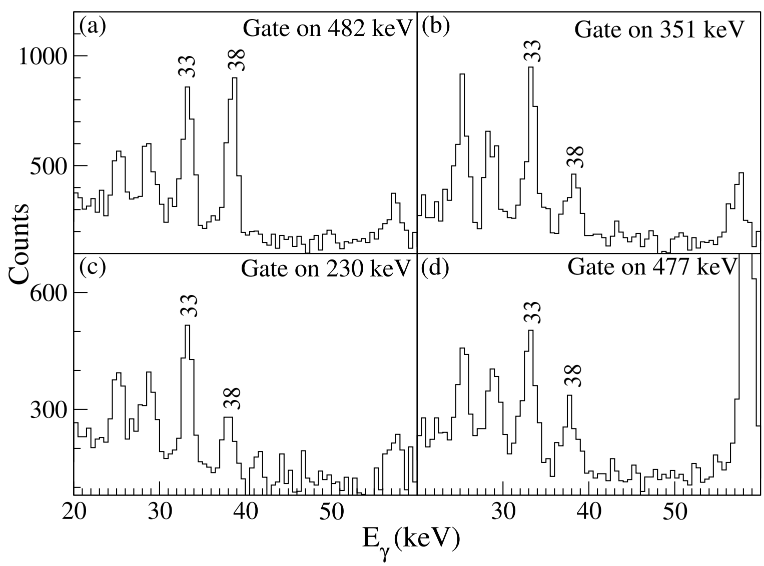

Fig. 2. Illustrative examples of spectra containing 33 keV and 38 keV peaks. Part (a) shows the intensity ratio ($I_\gamma(33)/I_\gamma(38)$) as 1:1.2 when 38 keV is the combined intensity of the X ray and γ ray gated with the coincident 482 keV transition in ^{132}La, while (b), (c) and (d) show the intensity ratio 1:0.25 for the X rays of La isotopes.

observed a distinct enhancement in the intensity ratio as 1:1.2. While we present here one example with energy gate on 482 keV γ ray of ^{132}La in Fig. 2 (a), there are many more coincident γ rays, *e.g.*, 279, 67 and 312 keV which exhibited the same enhanced intensity ratio. Thus, an association of 38 keV γ transition with the band $\pi h_{11/2} \otimes \nu h_{11/2}$ was confirmed.

3.2. Isomeric states

The presence of 38 keV transition helped us to identify [3] the isomeric multiplet states 7^+ and 8^+ $\hbar$ in the band with configuration $\pi h_{11/2} \otimes \nu h_{11/2}$, and lifetimes $\tau = 0.238$ ns and $\tau = 0.104$ ns, respectively. The experimental value of the decay probability 9.6×10^9 s^{-1} ($\tau = 0.104 \pm 0.008$ ns) for the bandhead 8^+ $\hbar$ was found to be too low and in complete disagreement with the theoretical value of 1.3×10^{13} s^{-1} from the Weisskopf estimate [4]. Therefore, we classified the bandhead (8^+ $\hbar$) as an isomeric state. Roberts *et al.* [5] discussed a similar structure in ^{134}Pr with multiple decays from a bandhead.

The isomerism is often related to the presence of forbidden decays. The hindrance comes from the fact that forbidden decays occur between states of completely different particle configurations. For instance, the $\pi h_{11/2} \otimes \nu h_{11/2}$ multiplet state 7^+ decays via hindered E1 transition to an opposite parity state 6^- which has the configuration $\pi[422]\frac{3}{2}^+ \otimes \nu h_{11/2}$ [6] and a long lifetime ($\tau = 24.3$ min). Similarly, bandhead 8^+ decays to 7^- state through the 350 keV E1 transition. A close look at the valence particle configurations suggests that the decays correspond to a change in the valence proton configuration $\pi h_{11/2} \to \pi(d_{5/2}/g_{7/2})$ from the initial state $\pi h_{11/2} \otimes \nu h_{11/2}$ to the final state $\pi(d_{5/2}/g_{7/2}) \otimes \nu h_{11/2}$, for which an E1 transition is forbidden in spherical nuclei by the selection rules of E1 operator. However, in deformed nuclei, $\pi h_{11/2}$ orbital picks up $f_{7/2}$ and $h_{9/2}$ components, while $\pi(d_{5/2} g_{7/2})$ picks up $g_{9/2}$ components; the mixed configurations allow E1 transitions. Since these admixtures are necessarily small, the resulting E1 matrix element is small as well which explains the relatively long lifetime. Finally, for the state 8^+, the two results — being isomeric and the bandhead for the configuration $\pi h_{11/2} \otimes \nu h_{11/2}$ — are consistent with each other. Other observed transitions decaying from the said 7^+ state, with energies 161, 279, 312 and 482 keV, also corresponded to the configuration change from $\pi h_{11/2} \otimes \nu h_{11/2}$ to $\pi(d_{5/2}/g_{7/2}) \otimes \nu h_{11/2}$. The 38 keV γ ray of our interest was an M1 transition, connecting two multiplet states 8^+ and 7^+ with the same particle configuration $\pi h_{11/2} \otimes \nu h_{11/2}$, and was reasonably intense [1, 2] despite being highly electron-converted.

4. Comparison with $^{130}_{55}$Cs$_{75}$ and $^{134}_{59}$Pr$_{75}$: Band assignment $\pi d_{5/2} \otimes \nu h_{11/2}$

Several bands with similar characteristics have been observed earlier among $N = 75$ isotones, *e.g.*, $^{130}_{55}$Cs$_{75}$ [7, 8], $^{132}_{57}$La$_{75}$ [1, 2] and $^{134}_{59}$Pr$_{75}$ [9]. For example, the bands with configurations $\pi d_{5/2} \otimes \nu h_{11/2}$ and $\pi g_{7/2} \otimes \nu h_{11/2}$ exist both in $^{130}_{55}$Cs$_{75}$ [8] and $^{134}_{59}$Pr$_{75}$ [9]. In Fig. 3, we compare the relevant part of the level schemes of $^{132}_{57}$La$_{75}$ [1] with $^{130}_{55}$Cs$_{75}$ [7, 8] and $^{134}_{59}$Pr$_{75}$ [9]. In both these neighboring nuclei, the band with configuration $\pi g_{7/2} \otimes \nu h_{11/2}$ is more strongly populated than the band with $\pi d_{5/2} \otimes \nu h_{11/2}$. Moreover, these two bands are interlinked to each other, shown as Band B and Band C in $^{130}_{55}$Cs$_{75}$ [8], Band 9 and Band 10 in $^{134}_{59}$Pr$_{75}$ [9]. In the case of $^{132}_{57}$La$_{75}$, earlier works [1, 6, 10] have discussed the band with configuration $\pi g_{7/2} \otimes \nu h_{11/2}$ but not the band with $\pi d_{5/2} \otimes \nu h_{11/2}$, and we expect it to be strongly populated because it exists in neighboring isotones. Figure 3 indicates the presence of the band with configuration $\pi d_{5/2} \otimes \nu h_{11/2}$ in $^{132}_{57}$La$_{75}$ because there is a strong resemblance with other nuclei, and it is also strongly linked with the band $\pi g_{7/2} \otimes \nu h_{11/2}$. Thus, we could assign Band 4 in Fig. 1 with configuration $\pi d_{5/2} \otimes \nu h_{11/2}$ which can be confirmed by theoretical models *e.g.* particle-rotor model.

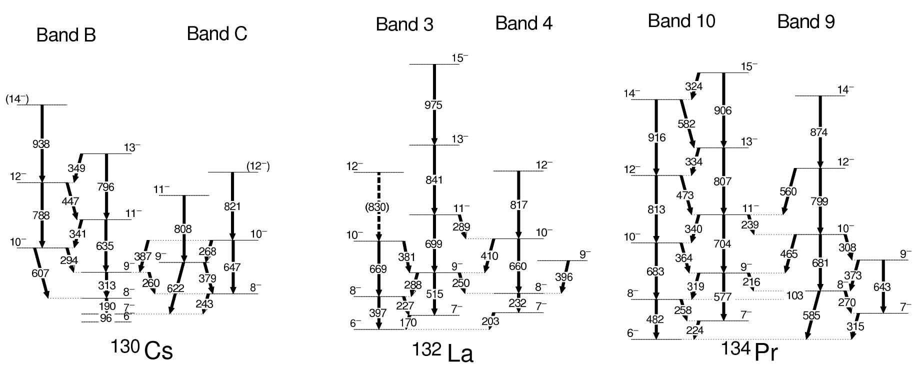

Fig. 3. A systematic comparison of $\pi g_{7/2} \otimes \nu h_{11/2}$ and $\pi d_{5/2} \otimes \nu h_{11/2}$ bands in $^{130}_{55}$Cs$_{75}$ [8], $^{132}_{57}$La$_{75}$ [1] and $^{134}_{59}$Pr$_{75}$ [9]. The configuration details are given in the text.

5. Summary

In our earlier study of ^{132}La [1], we found an energy gap of 38 keV between states 8^+ and 7^+ of configuration $\pi h_{11/2} \otimes \nu h_{11/2}$, without observing the gamma transition filling the gap. The present report described the identification of 38 keV γ ray from the intensity ratios ($I_\gamma(33)/I_\gamma(38)$) of omnipresent La X rays of energy 33 and 38 keV. The intensity ratio increased whenever 38 keV γ ray was present along with X ray of the same energy; the same ratio was found in all the spectra gated with γ-transitions coincident with 38 keV γ ray belonging to ^{132}La. Moreover, we observed a constant intensity ratio in ^{132}La as well as in ^{133}La when only the X rays were present. The observed states 8^+ and 7^+ were isomeric [3] due to hindered decays of E1 transition. The decay was allowed due to shape change between the initial and final configurations $\pi h_{11/2} \otimes \nu h_{11/2} \rightarrow \pi(d_{5/2}/g_{7/2}) \otimes \nu h_{11/2}$. We proposed a new configuration $\pi d_{5/2} \otimes \nu h_{11/2}$ to a known band [1] by comparing the level schemes of $^{130}_{55}$Cs$_{75}$, $^{132}_{57}$La$_{75}$ and $^{134}_{59}$Pr$_{75}$.

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