Three quasiparticle isomers in odd-even ^{159,161}Pm: Calling for modified spin-orbit interaction for the neutron-rich region[†]

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Nuclear properties of neutron-rich rare-earth nuclei at $Z \approx 60$ could be the possible key to answer one of the longstanding astrophysical questions: the formation of the $A \approx 160$ (rare-earth) peak observed in the elemental abundance distribution. From the nuclear-structure perspective, the formation of a peak in elemental abundance originates in extra stability of local nuclei. For example, in r-process, the neutron magic number $N = 82$ and $N = 126$ are responsible for the prominent abundance peaks at $A \approx 130$ and $A \approx 195$, respectively. Mumpower *et al.* identified that the nuclear properties of nuclei at $N \approx 100$ are critical to the rare-earth peak formation.[1)] In the case of the deformed rare-earth nuclei, a large shell gap between Nilsson single-particle orbitals stabilizes the nuclear shape at large deformation. Several theoretical works have predicted the existence of the deformed shell gaps at $N \approx 100$.[2)] Recently, a $6^- \ \nu(5/2[523] \otimes 7/2[633])$ state was discovered in ^{162}Gd$_{98}$,[3)] indicating the large shell gap at $N = 98$.

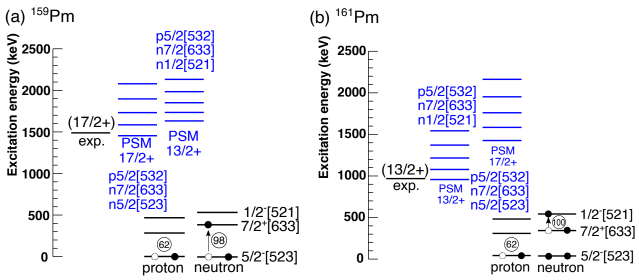

Fig. 1. Excitation energies of the isomers in (a) ^{159}Pm and (b) ^{161}Pm compared with the PSM calculation with the modified Nilsson parameters.

The spectroscopic study on neutron-rich rare-earth nuclei was performed at RIBF using the in-flight fission of ^{238}U^{86+} beam. The delayed γ rays were measured using a Ge detector array, EURICA.[4)] Accordingly, we discovered new quasi-particle isomers in ^{159,161}Pm$_{98,100}$. The 3-qp isomers involve one quasi-proton plus two quasi-neutrons near the Fermi surface as shown in Fig. 1. A calculation employing the projected shell model (PSM)[5)] was performed to understand the isomers. The observation of the (17/2+) isomers cannot be explained by the PSM calculation with traditional Nilsson parameters. We demonstrate that to explain the observation, the strength of the spin-orbit interaction needs to be changed according to the neutron number in exotic nuclei, as suggested by Liu *et al.*[6)] Furthermore, we also confirmed that the reported deformed shell gap at $N = 98$[3)] is present both in even-even and odd-mass nuclei.

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