Mirror symmetry at far edges of stability: The cases of ^{8}C and ^{8}He

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In nuclear systems, protons and neutrons interact with each other almost equally under the nuclear force. As a result, the level schemes of mirror nuclei, a pair of nucleus with interchanged numbers of protons and neutrons, show marked similarity by the so-called mirror symmetry. The energy difference of the corresponding excited states, called mirror energy difference (MED), is thus usually close to zero. However, a particular exception exists when a state is close to or above the particle emission energies. The MED of the weakly bound or unbound states with low-ℓ orbitals becomes large, which is known as the Thomas-Ehrman shift. In this study, we observed the first 2^+ state in ^{8}C for the first time, which is a four-proton unbound nucleus beyond the proton drip line.[1] This allows us to study the mirror symmetry between ^{8}C and ^{8}He via the 2^+ states, which are expected to be both unbound even though only the states in proton-rich nuclei are unbound by the Coulomb repulsive force in most of the mirror pairs.

We performed an experiment at GANIL with a radioactive ^{9}C beam produced by the LISE spectrometer. The recoiling deuterons from the ^{9}C$(p,d)^{8}$C reaction were detected to reconstruct the excitation energy of ^{8}C using the missing mass method. For the missing mass spectroscopy in inverse kinematics, two key devices, a thin liquid hydrogen target[2] and MUST2 telescopes,[3] were utilized. The liquid hydrogen target was developed based on the CRYPTA target system at RIKEN,[4] which is typically used with a thickness of 1 cm. We realized a thickness of 1.5 mm at the center of the target with a circular aperture of 20 mm. It was placed in a large volume chamber called M2C chamber (Fig. 1(a)). Six MUST2 telescopes (T1–T6) were placed to detect light recoiling particles from the reactions, as shown in Fig. 1(b). T5 and T6 were fixed by using an adjustable frame (Fig. 1(c)) to optimize the gap between two telescopes. Another experiment was also carried out with a common experimental setup as a campaign by using proton-rich Ca beams.[5–7] A schematic view of the full setup can be seen in Fig. 1 of Ref. 5).

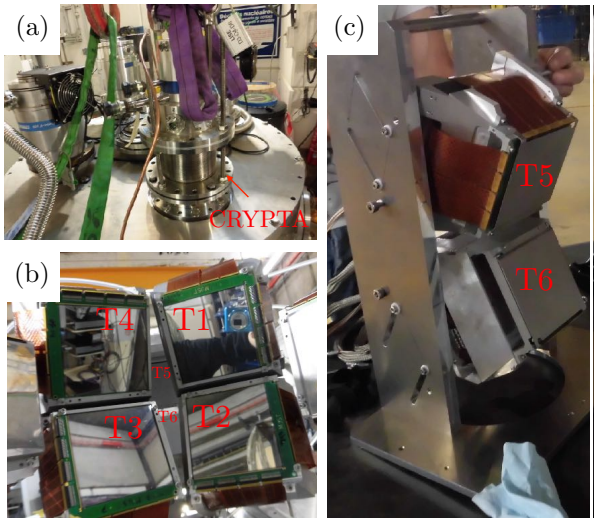

Fig. 1. Photographs of (a) CRYPTA fixed on top of the M2C chamber, (b) MUST2 telescopes seen from the upstream side, (c) T5 and T6 with an adjustable frame.

We successfully observed the first 2^+ state of ^{8}C at 3.40(25) MeV with a decay width of 3.0(5) MeV. The MED of $-0.14(25)$ MeV was obtained by comparison with the known first 2^+ state in ^{8}He. This is compatible with the MEDs of the first 2^+ states in the other even-even mirror pairs ever observed. To investigate the effect to the MED when the state was unbound, a two-body model calculation was performed by changing the potential depth. The small MED was understood from the evolution of resonance energies of the proton below and on top of the repulsive Coulomb potential.

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