New type of spectroscopy via heavy-ion double charge exchange (^{12}C, ^{12}Be(0^+_2)) reaction

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One of the most interesting features in atomic nuclei is the variety of spin and isospin responses. The Gamow–Teller (GT) transition is the simplest spin–isospin response within one-phonon excitations, and it has been well studied. In contrast, data on multi-phonon excitations have been scarce. The double GT giant resonance (DGTGR)1) is the most basic two-phonon excitation mode. However, DGTGRs have not been observed so far. The discovery of the DGTGR is an essential step in extending the research of the spin–isospin responses to multi-phonon space. Another interest for studying DGTGR relates to its relevance in neutrino physics; the DGT transition is induced by the same transition operator as the $\beta\beta$-decay is , *i.e.*, $\sigma\tau\sigma\tau$. However, the $\beta\beta$-decay has quite small DGT strength. A major part of the DGT strength is concentrated among highly excited states in DGTGR. A promising spectroscopic method to search for DGTGRs is through heavy-ion double charge exchange (HIDCX) reactions, which can induce two-phonon excitations with spin and isospin transfer by two units.

In 2011, we conducted a HIDCX ^{12}C(^{18}O, ^{18}Ne)^{12}Be reaction experiment and found a large cross section of 1.5 μb/sr for the second 0^+ (0^+_2) state in ^{12}Be at 0°2). This is probably because all the initial ^{12}C($0^+_{\mathrm{g.s.}}$), intermediate ^{12}B($1^+_{\mathrm{g.s.}}$), and final ^{12}Be(0^+_2) states are dominated by a $0\hbar\omega$ configuration3–5). This led us to a new idea to use the (^{12}C, ^{12}Be(0^+_2)) reaction as a tool to investigate DGTGRs. In this probe, the excitation energy of target nuclei are measured using a missing–mass technique. Several final states in ^{12}Be can degrade the signal-to-noise ratio of an observed spectrum in the method. The key of this probe is to avoid the contamination by tagging the two 511–keV γ-rays emitted back-to-back from the e^+e^- decay with the mean lifetime of 331 ns6). In order to demonstrate the feasibility of the delayed γ-ray tagging method, we performed the HIDCX ^{18}O(^{12}C, ^{12}Be(0^+_2))^{18}Ne reaction measurement using the Grand Raiden (GR) spectrometer at RCNP, Osaka University. The primary ^{12}C beam at 100A MeV bombarded a 20-mg/cm^2 H$_2{}^{18}$O ice target. The momenta of outgoing particles were analyzed using GR. The two 511–keV γ-rays from ^{12}Be(0^+_2) were detected using a NaI(Tl) array surrounding a plastic-scintillator stopper at the GR focal plane. Figure 1 shows the GR horizontal position spectra. The position corresponds to the excitation energy of ^{18}Ne. The peak of the spectrum without the γ-ray tagging, which originates from the ^{18}Ne ground state, is rather broad and has a tail. The broadening is probably due to contributions from different final states in ^{12}Be, and the tail originates from accidental coincidence events of ^{9}Li and ^{6}He. On the other hand, in a red spectrum with γ-ray tagging, the peak indicated by a red arrow is narrower, and the background has mostly vanished. The obtained energy resolution was ∼3 MeV mainly because of an energy–loss difference in the target, and thus the difference between the peak positions of the two spectra is within the resolution. The result of the test experiment shows the feasibility of the gamma-ray tagging method. Our next step is to apply this method to nuclei exhibiting $\beta\beta$-decay, such as ^{48}Ca.

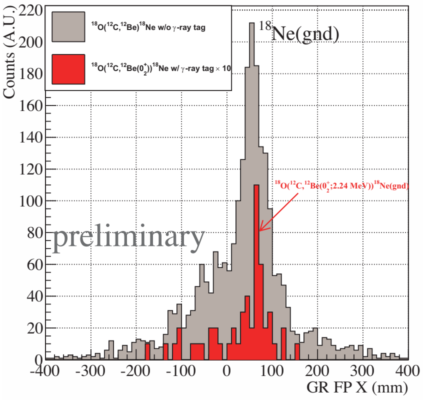

Fig. 1. Horizontal position spectra of the GR focal plane with or without γ-ray tagging. For the red spectrum, detection efficiency of 10% is considered for the NaI(Tl) array.

References

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