論文の内容の要旨

Spectroscopy of resonance states in light proton-rich nuclei via missing mass method

(欠損質量法を用いた軽い陽子過剰核における共鳴状態の分光)

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In this thesis, an experimental study for excited states of proton-rich ^{8}C is described. The atomic nucleus is a finite quantum many-body system consisting of two kinds of particles, protons and neutrons. These particles in a nucleus interact with each other by the nuclear force as well as the repulsive Coulomb force for each proton pairs. Many observables have been measured in many kinds of nuclei. These observables have been described theoretically by using model calculation. In light nuclei, some specific correlations such as the cluster structure were suggested and have been investigated by model calculations. For direct descriptions of nuclei without any model, significant progress of *ab initio* calculations has been made in recent years. *Ab initio* calculations in nuclear physics start from the fundamental forces among protons and neutrons and aim at predicting properties of nuclei. As a result of the calculations, some specific correlations in nuclei have appeared such as the cluster structure composed of two α particles in ^{8}Be. These correlations are expected to appear in light nuclei, especially in unstable nuclei and excited states in stable nuclei. Therefore, it is essential to accumulate experimental observables of light unstable nuclei and excited state of stable nuclei.

In the present study, excited states of proton-rich ^{8}C state are experimentally investigated. Only the ground state of ^{8}C was experimentally observed in several experiments. In ^{8}He, the mirror nucleus of ^{8}C, the first excited 2^{+} state was experimentally observed at 3.5-3.6 MeV with a total decay width of about 1 MeV. A broader total decay width is expected for the mirror excited state in ^{8}C and it is not obvious that the mirror symmetry is still preserved even in such a broad resonance. For the spectroscopy of ^{8}C, the missing mass method was used with RI beams. The resonance states of our interest are expected to decay via multi-particle emission such as an α particle and four protons emission from ^{8}C. The single-particle detection for the missing mass is more efficient than the multi-particle detection of the decay fragments. The neutron transfer (p,d) and (p,t) reactions were used to populate resonance states of ^{8}C. The deep hole s wave resonance may be populated in the (p,d) reaction as in the case of the $^{6}Li(p,d)^{5}Li$ reaction. The practical advantage of the (p,d) and (p,t) reactions is relatively high kinematic energy of the recoil particle from the target due to the large negative Q-value of the reactions. The large kinematic energy allows us to use a thick hydrogen target without losing the energy resolution of the excitation energy spectra by the missing mass method.

We performed the experiment to search for excited states in ^{8}C at the accelerator facility GANIL with a ^{12}C primary beam. Resonance states in ^{8}C were populated via the (p,d) and (p,t) reactions with the proton-rich ^{9}C and ^{10}C secondary beams of 55 MeV/u and a liquid hydrogen target with a thickness of 1.5 mm at the center. The energy-degraded ^{12}C was also used as a reference data. Resonance states in ^{7}B, ^{6}Be and ^{5}Li were simultaneously measured via the (p, d) reaction in the same setup with the ^{9}C secondary beam including ^{8}B, ^{7}Be and ^{6}Li. The incident beam particles were particle identified by the TOF measurement on event-by-event bias. Recoil particles and some of the decay fragments from the reactions were detected by an array of the MUST2 telescopes with double-sided silicon strip detectors (DSSDs) and a thallium doped CsI scintillation detectors.

The data was analyzed to obtain the excitation energy spectra by the missing mass method. The specific analysis was performed to correct the hit position dependence of the energy deposit in CsI crystals of the MUST2 telescopes, which had not been observed in the previous experiments with the same detectors. The dependence was corrected by virtually dividing the CsI crystal in pixels with the hit positions measured by DSSDs. The E-ΔE correlation was used as a reference for the correction. The reasonable excitation energy resolution as the previous experiment with almost the same setup was obtained after the correction.

The results of the $^{12}C(p,d)^{11}C$ and $^{12}C(p,t)^{10}C$ reactions were used as reference reactions to evaluate the validity of the present experiment. The agreement with the previous experiments of the $^{12}C(p,d)^{11}C$ and $^{12}C(p,t)^{10}C$ reactions showed that the present experiment was performed successfully. The systematic error was estimated from these reactions.

The obtained spectrum of the $^{9}C(p,d)^{8}C$ reaction was fitted with response functions for resonance states based on *R*-matrix theory and non-resonance distributions. The newly observed resonance states are summarized in Table 1. The first 2^+ state of ^8C was newly observed at 3.4(2) MeV with the broad decay width of 3.0(4) MeV. The moderate value of the mirror energy difference of the first 2^+ states in ^8C and ^8He suggests the mirror symmetry is preserved even with the broad decay width of ^8C.

The same fit was performed for the spectra of the $^{8}B(p,d)^{7}B$ and $^{7}Be(p,d)^{6}Be$ reactions. The intense resonances around 17 MeV were also newly observed systematically in the proton-rich N = 2 isotones ^8C, ^7B and ^6Be as in the case of the $^{6}Li(p,d)^{5}Li$ reaction. These resonances among N = 2 isotones understood as the deep hole *s* wave resonance.

Table 1 Summary of the newly observed resonance states. Resonance energy (*E*r), total decay width (Γ) at the resonance energy, reduced decay width (γ^2), channel radius (*a*), significance level (S. L.) and main decay channel are shown.

	E_r [MeV]	$\Gamma(E_x = E_r)$ [MeV]	γ^2 [MeV]	a [fm]	S. L.	decay channel
^8C	3.4(2)	3.0(4)	4.3(6)	4.2	6.9σ	α
^8C	18.1(3)	3.9(9)	-	-	3.1σ	^3He
^7B	3.2(2)	3.0(4)	4.3(6)	4.1	5.2σ	α
^7B	16.2(3)	5.6(9)	-	-	5.7σ	^3He
^6Be	16.1(3)	3.0(4)	-	-	6.5σ	^3He