Excitation of the Lowest 0^+ State in ^<12>N through the (△J △L, △S) = (0,1,1) Channel in the (p,n) Reaction on ^<12>C at E_p = 35MeV

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I. 2. Excitation of the Lowest 0^+ State in ^{12}N through the (ΔJ, ΔL, ΔS)= (0,1,1) Channel in the (p,n) Reaction on ^{12}C at E_p= 35MeV

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The (p,n) reaction is a promising tool to study the isospin and spin-isospin excitation modes in nuclei, such as the isobaric analog state (IAS) and Gamow-Teller (GT) resonance. The low energy (p,n) reaction[1-3] provides better energy resolution of the excited spectra than the intermediate (p,n) reaction. The proton neutron paring in $N = Z$ nuclei is the subject under intensive studies. There are nine stable $N = Z$ nuclei in the mass table. However, the 0^+ $T = 1$ state is found experimentally only in ^{12}C at 17.77 MeV. Thus it is interesting to study by the (p,n) reaction the correlations in $T = 1$, $J = 0$ state of ^{12}N at 2.43 MeV, which is the analog state of ^{12}C at 17.77 MeV.

Cecil et al.[4] have carried out the spin parity-assignments for the 2.43-MeV state, its existence being reported by ^{10}B($^3He,n$)^{12}N[5] reaction, to be 0^+ by studying analog relation between ^{12}C($^3He,t$)^{12}N and ^{12}C($^3He,^3He'$)^{12}C* reactions exciting 2.43 and 17.77 MeV states, respectively. However, more direct evidence have been awaited for. They measured as well the differential cross sections for the ^{14}N(p,t)^{12}N reaction leading to the 2.43-MeV state, and interpreted the angular distribution by those with the two-step process.

Reliability of the information obtained from DWBA analysis of low-energy (p,n) data has been discussed in detail by Ohnuma et al.[5] with ^{12}C(p,n)^{12}N and ^{16}O(p,n) ^{16}F reaction at E_p= 35 and 40 MeV. If one assume the pure $(1p_{3/2})^8$-configulation for the ground state of ^{12}C, the direct charge-exchange process cannot excite the $J = 0$, $T = 1$ state in ^{12}N, since $(1p_{1/2})_\pi(1p_{3/2})_\nu$ configuration does not couple to the $J = 0$, $T = 1$ state. Therefor, the strong ground state correlations might be crucial to observe the $J = 0$, $T = 1$ state in ^{12}N through the direct (p,n) reaction process on ^{12}C.

In this report we present observation of the 2.43-MeV state by the high-resolution low-energy (*p,n*) reaction. The cross-section magnitudes and their angular distribution is explained reasonably by the microscopic distorted wave analysis with knock-on exchange effects, where one body transition densities (OBTD), derived from the precise shell-model wave function, are taken into accounts.

The experiment was performed at the Cyclotron and Radioisotope Center, Tohoku University, with a 35-MeV proton beam from an AVF-cyclotron and a beam swinger system. The details of the experimental setup were described elsewhere[6,7]. Neutron energies were measured by the time-of-flight technique (TOF), where neutrons were detected by a detector array located at 44.3 m from the target. The ten detectors, 23.2 liters in the total sensitive volume, were filled with organic liquid scintillator NE213. The absolute efficiencies of the detectors were obtained from the ^{7}Li(*p,n*)^{7}Be activation analyses with an error less than 6%. The errors in the absolute magnitude of (p,n) cross sections were estimated to be less than 12%. The targets were a carbon foil enriched to 99% in ^{12}C with the thickness of 2.0mg/cm^2, prepared by the clacking method.

Figure 1 shows the neutron energy spectrum of the ^{12}C(*p,n*)^{12}N reactions measured at θ_{lab} = 0°. In addition to the prominent isolated peaks of neutrons leading to the 1^+ ground- and 2^+ 1.19-MeV states, peaks due the 2.43-MeV state is clearly seen. Differential cross sections of the ^{12}C(*p,n*)^{12}N reaction exciting the 0^+ 2.43-MeV state are shown in Figs. 2, and those for the 1^+ ground-state is shown in Fig. 3 as well for comparison purpose. Curves in the figures are results of the microscopic DWBA analyses.

The microscopic DWBA results are obtained by using shell model wave functions for the computer code DWBA-70[8], which takes into accounts knock-on exchange effects properly. The optical potential parameters of Becchetti and Greenlees[9] are used for the entrance channel. Those for the exit channel are the self-consistent potential parameters derived by Carlson et al[10]. The effective nucleon-nucleon interactions used in the present DW analysis are M3Y interactions by Bertsch et al[11]. A sensitivity of the calculations to the optical-potential parameters is elaborated in Ref. 5. The one body transition densities (OBTD) for the microscopic DWBA calculation are obtained by the shell-model computer code OXBASH[12]. The latter for the prominent $0^+ \rightarrow 0^+$ is listed in Table1, together with those for the prominent $0^+ \rightarrow 1^+$ transition to the ground state of ^{12}N.

In an ordinary one-step zero-range direct reaction, the $0^+ \rightarrow 0^+$ transition proceeds through [ΔJ, ΔL, ΔS] = [0, 0, 0] channel, thus the angular distribution of deferential cross section for such a $0^+ \rightarrow 0^+$ transition may exhibits the similar shape with that for the $0^+ \rightarrow 1^+$

transition, which proceeds though the [1, 0, 1] channel showing typical $\Delta L = 0$ pattern as shown in Fig. 3. The striking difference between these two angular distribution patterns is remarkable. The latter for the $0^+ \rightarrow 1^+$ transition in Fig. 3 exhibits the normal bell-shape for an $L = 0$ transition, familiar to that for the prominent GT-type (p,n) reaction[13]. On the other hand, the $0^+ \rightarrow 0^+$ transition to the 2.43-MeV state shows the 0-degree peaked angular distribution with highly hindered cross-section magnitudes, suggesting the existence of other kinds of reaction dynamics encountered into this transition.

As listed in Table 1, the main contributions for the $0^+ \rightarrow 1^+$ transition are $1p_{1/2} \leftarrow 1p_{3/2}$ and $1p_{3/2} \leftarrow 1p_{1/2}$, while they are $1p_{1/2} \leftarrow 1p_{1/2}$ and $1p_{3/2} \leftarrow 1p_{3/2}$ for the $0^+ \rightarrow 0^+$ transition. These magnitudes themselves are quite large suggesting strong ground state correlations in ^{12}C. Hindrance of the cross-section in the $0^+ \rightarrow 0^+$ transition might be due to significant cancellation between two contributions. Thus, the origin of observed cross section s is the non-local exchange contributions through the $[\Delta J, \Delta L, \Delta S] = [1, 1, 0]$ channel.

In summary, the weakly populated 0^+ state was firstly observed by the (p,n) reaction with high resolution measurement at $E_p = 35$ MeV. By the analysis with microscopic DW theory, it was found that the [1, 1, 0] channel exchange process played the dominant role.

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Table 1. One body transition densities for the $0^+ \rightarrow 0^+$ and $0^+ \rightarrow 1^+$ transitions in the ^{12}C(p,n)^{12}N reaction calculated by the shell-model code OXBASH with the full psd model-space by psdmwk-interactions defined in the code OXBASH.

Particle-hole configuration	$0^+ \rightarrow 0^+$	$0^+ \rightarrow 1^+$
$1p_{1/2} \leftarrow 1p_{1/2}$	-0.45989	-0.04406
$1p_{1/2} \leftarrow 1p_{3/2}$	-	-0.71360
$1p_{3/2} \leftarrow 1p_{1/2}$	-	-0.32507
$1p_{3/2} \leftarrow 1p_{3/2}$	0.33419	-0.06326
$1d_{3/2} \leftarrow 1d_{3/2}$	0.00048	0.00025
$1d_{3/2} \leftarrow 1d_{5/2}$	-	-0.00238
$1d_{3/2} \leftarrow 2s_{1/2}$	-	-0.00031
$1d_{5/2} \leftarrow 1d_{3/2}$	-	-0.00036
$1d_{5/2} \leftarrow 1d_{5/2}$	-0.00771	-0.0041
$2s_{1/2} \leftarrow 1d_{3/2}$	-	0.00021
$2s_{1/2} \leftarrow 2s_{1/2}$	-0.00005	-0.00031

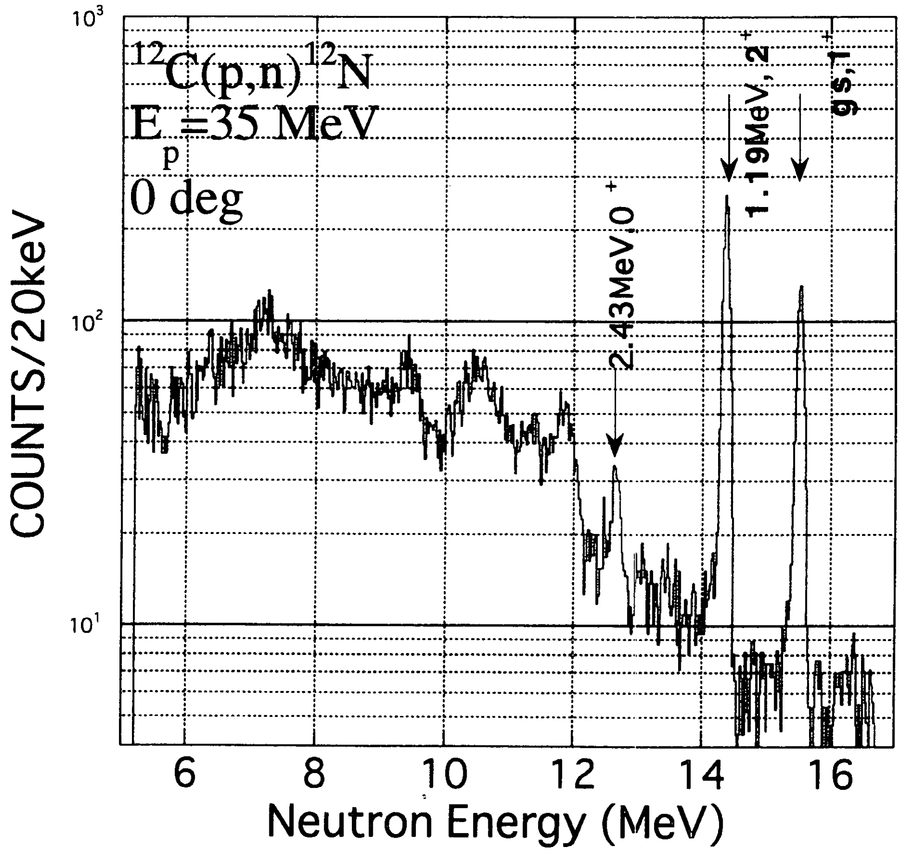

Fig. 1. Energy spectrum of the ^{12}C(p,n) ^{12}N reaction at $\theta_{lab} = 0°$ with a flight path of 44.3 m. Energy per channel is 25 keV.

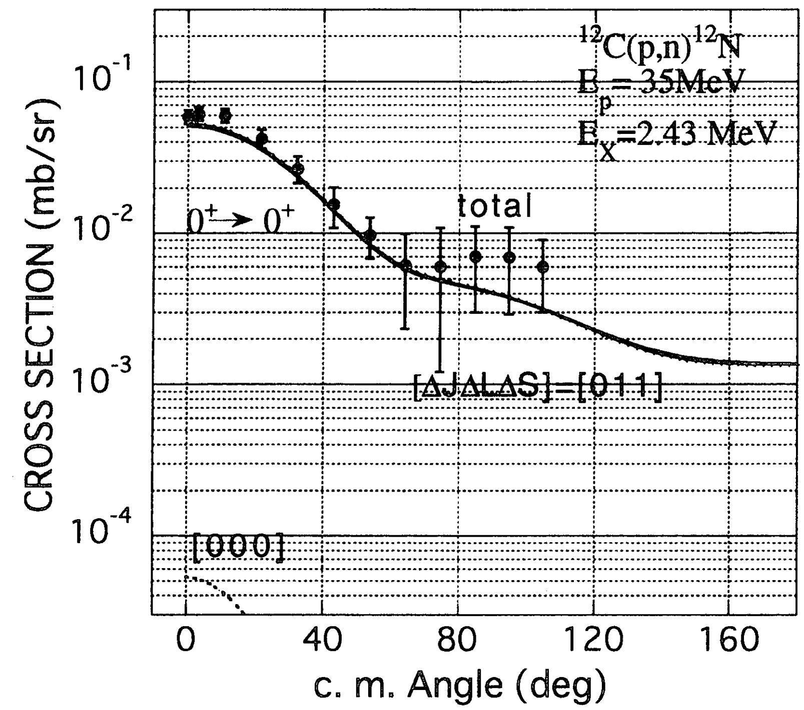

Fig. 2. Differential cross sections for neutrons leading to the 0^+ state at E_x = 2.43MeV in ^{12}N. The curves are DWBA results described in the text.

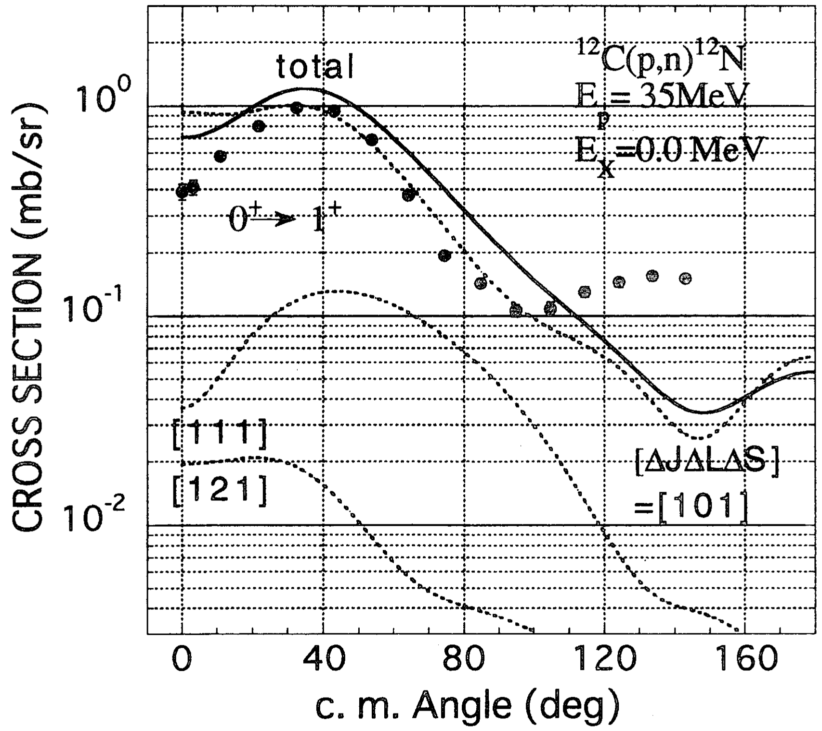

Fig. 3. Differential cross sections for neutrons leading to the 1^+ state at E_x = 0.0 MeV in ^{12}N. The curves are DWBA results described in the text.