$^{12}C(p,n)^{12}N$ Reaction at $E_p = 70$ MeV: Reliability of the information obtained from DWBA analysis of 70-MeV (p,n) data

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Intermediate energy (*p,n*) reaction have been proved(1) to be an excellent tool to study spin-isospin excitation modes of nuclei. High sensitivity of the spin-flip excitation mode due to relatively strong spin-dependent interaction has been utilized in such studies(1). Furthermore interpretation of the data in terms of the distorted-wave impulse approximation (DWIA) is expected to be reliable at reasonably high incident energies. Low-energy (*p,n*) reactions at e.g. E_p= 35MeV(2) are considered to be less transparent in their interpretation, because of the strong spin-independent interaction, relative importance of the distortion effect and the exchange process, ambiguities in the effective interaction, possible contributions from higher-order processes, etc. In low-energy (*p,n*) experiments, on the other hand, much better energy resolution can be achieved, making them very attractive to nuclear structure studies. The (*p,n*) reaction experiments at E_p= 50 ~ 100MeV, where spin flip strength dominates over spin non-flip one and higher resolution is expected, may provide a new fields for exploration of the nuclear spectroscopy.

It is necessary therefore first to test the reliability of the information obtained from the (*p,n*) reaction at E_p= 70 MeV, and second to compare such information with that from intermediate- and low-energies works. The $^{12}C(p,n)^{12}N$ reaction suits these purposes very well. The structure of mass 12 nucleus has been studied in detail, and shell-model wave functions is available, which describe various properties of these nuclei reasonably well. This reaction, as well as the (*p,p'*), (*n,p*) and ($^3He,t$) reactions to the analog final states, has been studied extensively at various energies(3-8). In this report we discuss a high-resolution study of the $^{12}C(p,n)^{12}N$ reaction leading to the low-lying states in the final nuclei at the incident proton energies of 70MeV. A detailed comparison of the results with DWBA calculations and with the results obtained at intermediate energies is given.

The experiment was performed using 70MeV proton beams from the K= 110MeV AVF cyclotron and the time-of-flight facilities[9)] at the Cyclotron and Radioisotope Center, Tohoku University. We have utilized a beam swinger system, and measured angular distributions of emitted neutrons between 0° and 60°. The ^{12}C target was 20 mg/cm^2 thick self-supporting foil of natural abundance. Overall time resolution was less than 1 ns. The detector efficiencies were calibrated at various neutron energies by using the ^{7}Li(p,n)^{7}Be reaction. The measured neutron yields are compared with the residual radioactivity from ^{7}Be to determine the absolute efficiencies of the detectors. They are found to be in good agreement with Monte Carlo caclulations. The errors in the absolute magnitude of the cross sections are estimated to be less than 15% .

Figures 1 illustrates the neutron excitation-energy spectrum measured at a laboratory angles of 0 and 35 degree for the ^{12}C$(p,n)^{12}$N reaction at E_p = 70 MeV. Curves in the figure are results of the phase space calculation for three-body break up, and those of peak fitting for the low-lying together with the high-laying proposed states. Measured angular distributions are displayed in Figs. 2-5 along with the DWBA calculations described below.

The data are compared with microscopic DW results calculated by the computer code DWBA-74[10)], which includes knock-on exchange effects in an exact manner. Note that fully antisymmetrized calculations were made in the present microscopic DW analysis, in which non-normal parity terms also contribute to the cross section. Optical potential parameters of Nadasen et al.[11)] were used for the entrance channel. Those for the exit channel were potential parameters derived by Varner et al.[12)] The effective nucleon-nucleon interactions used in the present DW analysis were those by Franey and Love[13)]. Spectroscopic amplitudes (OBTD) for the microscopic DWBA analysis were obtained from shell model calculations, where psd model-space has been taken into accounts up to $4\hbar\omega$-jump configurations using the code OXBASH[14)] with the interaction of Cohen, Kurath and Millener[15)]. As for the single-particle radial wave functions used in DW calculations were generated in a Wood-Saxon type bound-state potential with r_0 = 1.25 fm, a = 0.65 fm and V_{LS} = 6 MeV, and the depth adjusted to reproduce the binding energy of the last neutron or proton.

Figure 2 illustrates experimental and theoretical angular distribution of cross sections for the (p,n) reaction on ^{12}C leading to the ground 1^+ and first excited 2^+ states in

^{12}N. Remarkably reasonable fitting with DW calculations mentioned above has been obtained. An important point to be noted is that calculations with the FL-100 effective interaction give much better explanation for the experimental cross sections, while those with the FL-50 effective interaction over estimate similarly to the cases in the analysis for the $^{6}Li(p,n)^{6}Be$ reaction at E_p= 70 MeV$^{16)}$. The cross sections for the 0^+ to 2^- transition are absolutely fitted as well with the DW calculation as shown in Fig. 3.

Beyond the excitation energy of 3MeV in ^{12}N or ^{12}B, many authors have discussed on spin-parity assignments for the observed transitions by charge-exchange reactions on $^{12}C^{3\text{-}8)}$. A peak is seen at E_x =3.5 MeV in the neutron spectrum measured at 35° illustrated in Fig. 1. The most provable spin-parity assignment for this state may be 2^+ predicted by shell model as second 2^+ state. Comparison with the calculation for differential cross sections is shown in Fig. 3.

In addition, two prominent and one broad peeks are observed in the neutron spectrum. The angular distribution of cross sections corresponding to the broad peak at ~4.2MeV is fitted with the sum of $\Delta J^{\pi} = 2^-$ and 4^- transitions as illustrated in Fig. 4, where both theoretical predictions are multiplied by a factor of 0.35, suggesting that the shell model predictions for the transition strength too much concentrated on the transitions to the second 2^- and first 4^- state. Figure 4 shows the results for the transition to the 5.3 MeV-peek. The spin-parity assignment of $\Delta J^{\pi} = 3^-$ for this state seems to be reasonable. The last debate for the analyses of the differential cross sections is for the broad peak spreading over $E_x = 6 - 8$ MeV in ^{12}N as seen clearly at the 0-degree neutron spectrum in Fig. 1. The angular distribution exhibits the typical $\Delta L = 1$ pattern as illustrated in Fig. 5. The experimental cross sections are fitted with sum of predictions over 6, $\Delta L = 1$ transitions. The DW cross sections are multiplied by a factor of 0.5. Other strength may be presumably scattered into higher excited states.

In a summary, an experimental study of the $^{12}C(p,n)^{12}N$ reaction have been carried out at E_p= 70 MeV with better resolution than those so far reported. Results were compared successfully with the predictions based on large-space shell-model and DW calculations where Franey and Love 100MeV effective interactions were applied. Spin-parity assignments for observed seven transition were consistent with previous report.

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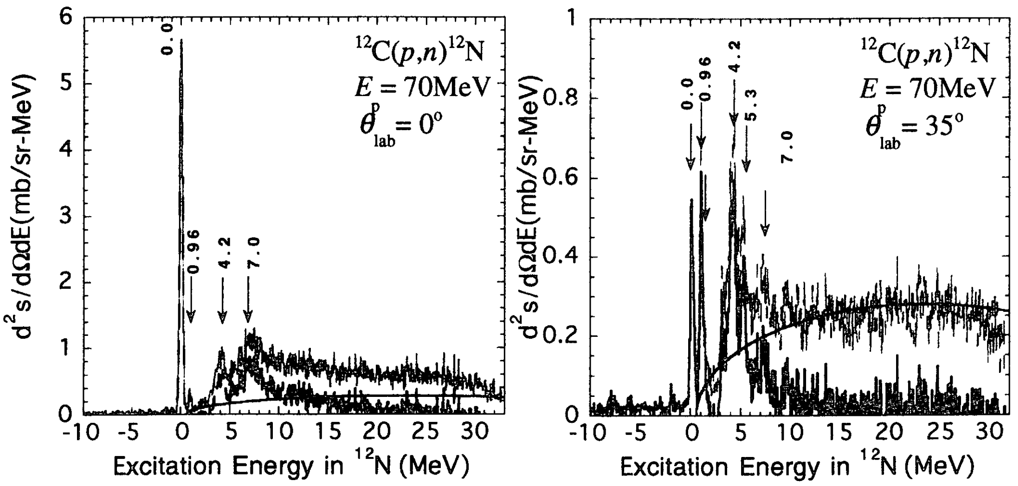

Fig. 1. Sample excitation energy spectra from the ^{12}C(p,n) ^{12}N reaction taken at 0° and 30° with a flight path of 44.3 m. Energy per bin is 50 keV.

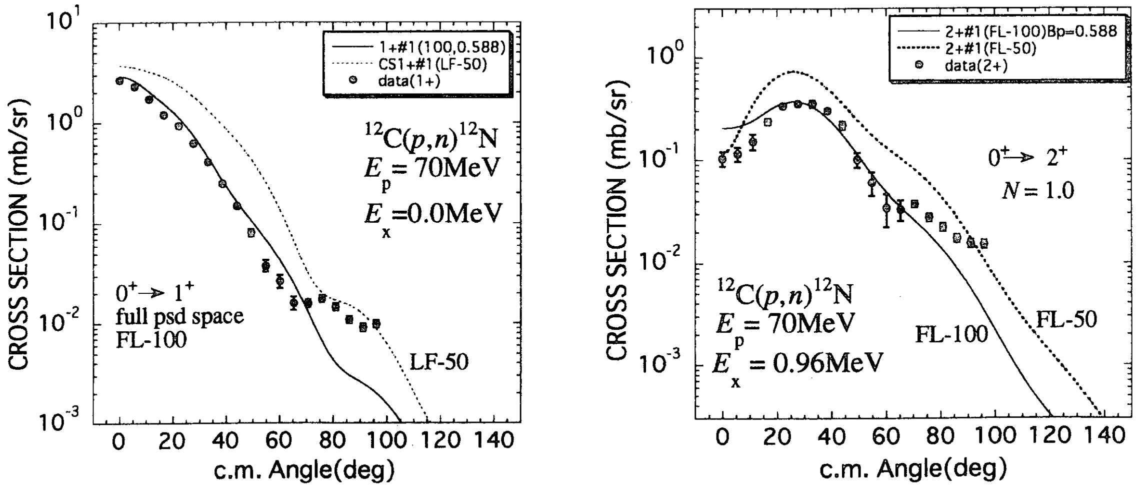

Fig. 2. Differential cross sections for neutrons leading to the ground and 0.96-MeV states in ^{12}N.

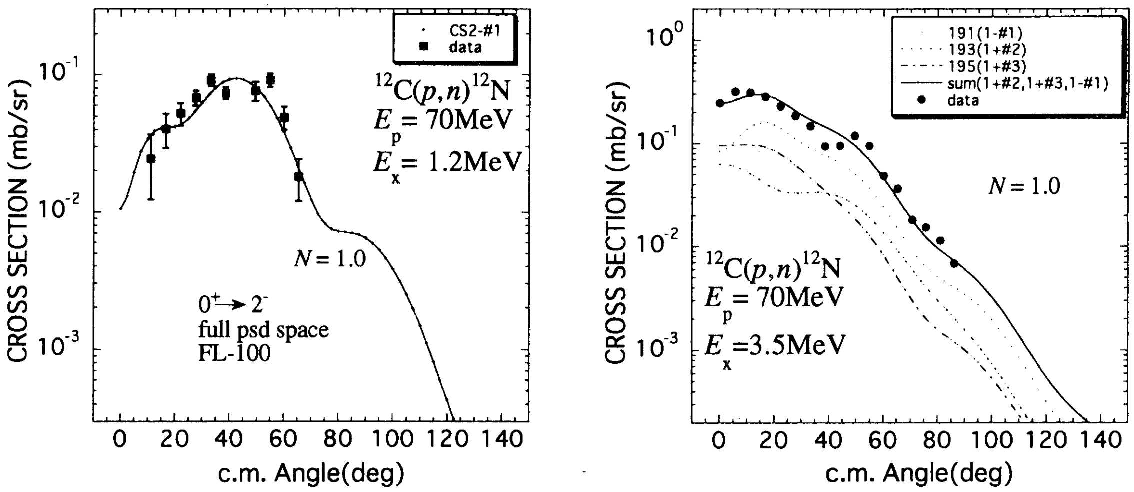

Fig. 3. Differential cross sections for neutrons leading to the 1.2 and 3..5-MeV states in ^{12}N.

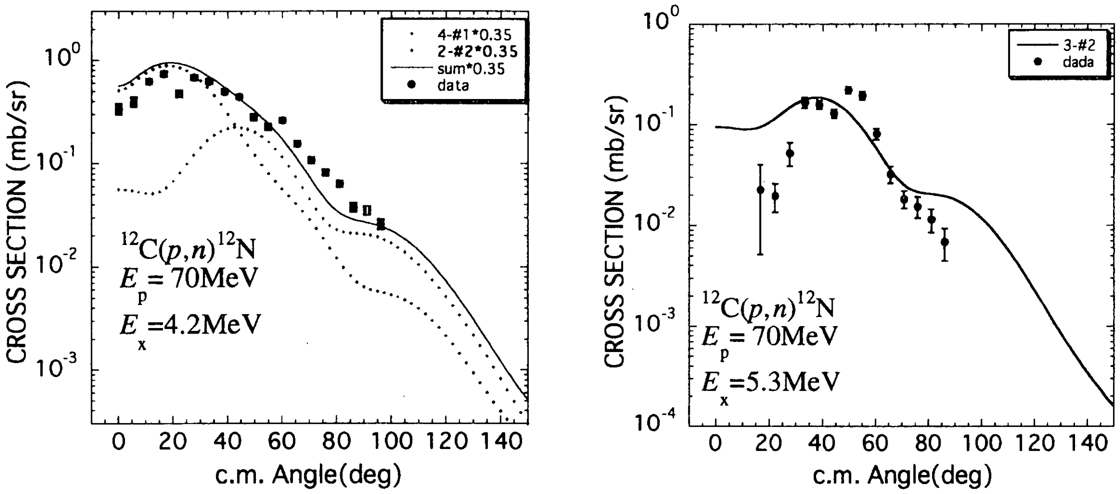

Fig. 4. Differential cross sections for neutrons leading to the 4.2 and 5.3-MeV states in ^{12}N.

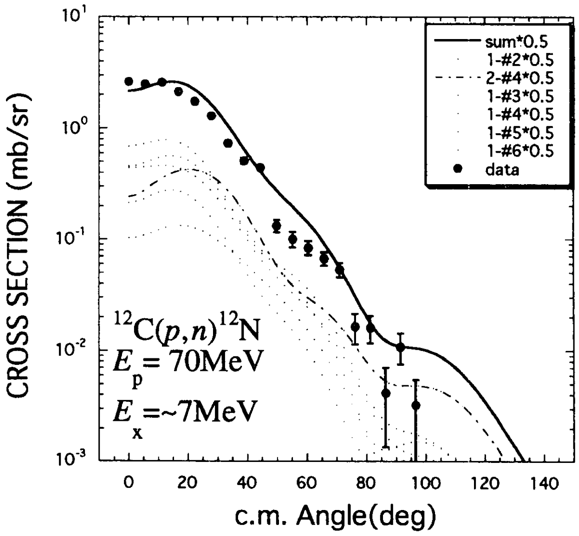

Fig. 5. Differential cross sections for neutrons leading to the ~7-MeV state in ^{12}N.