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Study of $^{12}C(p, n)^{12}N$ reaction at 70MeV

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Intermediate energy (p,n) reaction have been proved 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 inter-action has been utilized in such studies. In low-energy (p,n) experiments, on the other hand, much better energy resolution can be achieved[1], making them very attractive to nuclear structure studies. The (p, n) reaction experiments at E_p = 70MeV, where spin-flip strength dominates over spin non-flip one and higher resolution is expected, may provide new fields for exploration of the nuclear spectroscopy. It is necessary first, however, to test the reliability of the information obtained from the (p, n) reaction at E_p= 70MeV, and to compare such information with those from intermediate-[2] 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 are 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. 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 energy of 70MeV. A detailed comparison of the results with DWBA(distorted wave Born approximation) calculations and with the results obtained at intermediate energies is given.

The experiment was performed using 70MeV proton beam from the K= 110MeV AVF cyclotron and the time-of-flight facilities at the Cyclotron and Radioisotope Center, Tohoku University[3]. We have utilized a beam swinger system, and measured angular distributions of emitted neutrons between 0^o and 90^o in the laboratory system. 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 $^7Li(p,n)^7Be$ reaction. The measured neutron yields are compared with the residual radioactivity from ^7Be to determine the absolute efficiencies of the detectors. They are found to be in good agreement with Monte Carlo calculations. The errors in the absolute magnitude of the cross sections are estimated to be less than 15%. Figure 1 and 2 illustrates the neutron excitation-energy spectrum measured at a laboratory angles of 0 and 35 degrees for the $^{12}C(p,n)^{12}N$ reaction at E_p=70MeV.

Curves in the figure are sum of results of the phase space calculation for three-body break up and background caused by ^{13}C,and those of peak fitting for the known low-lying states together with the high-lying presently proposed states. Measured angular distributions are displayed in Fig.3 along with the DWBA calculations described below. The data are compared with microscopic DW results calculated by the computer code DWBA74[4],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 Schwandt et al. were used for the entrance channel. Those for the exit channel were derived by Varner et al. The effective nucleon-nucleon interactions used in the present DW analysis were those by Franey and Love[5]. Spectroscopic amplitudes (One Body Transition Density) for the microscopic DWBA analysis were obtained from shell model calculations, where psd model-space has been taken into accounts up to $2\hbar\omega$ jump configurations using the code OXBASH with the interaction of Cohen-Kurath and Millener. 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= 1.25fm, a= 0.65fm and V_{LS}= 6MeV. The depth of potential adjusted to reproduce the binding energy of the last neutron or proton. First and second part in left side of Fig. 3 illustrates experimental and theoretical angular distribution of cross sections for the (p,n) reaction on 12C leading to the ground 1^+ and first excited 2^+ states in ^{12}N. Remarkably reasonable fitting with DW calculations mentioned above has been obtained. A point to be noted is that calculations with the FL-100MeV effective interaction give much better explanation for the experimental cross sections, while those with the FL-50 effective interaction overestimate too much. The cross sections for the 1^+ 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. The most provable spin-parity assignment for E_x=3.5MeV state may be sum of two 1^+ states and one 1^- state predicted by the shell model. Comparison with the calculation for differential cross sections is shown in Fig.3. In addition, two prominent and one broad peaks 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 predictions for the second 2^- and the first 4^- states. Spin-parity assignment of 3^- for the transition to the 5.3MeV-peak seems to be reasonable. The last debate for the analysis of the differential cross section is for the broad peak spreading over E_x= 6-8 MeV in ^{12}N as seen clearly at the 0° neutron spectrum in Fig. 1. The experimental cross sections are fitted with sum of predictions over 6, ΔL=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, reliability for nuclear physics study with 70-MeV (p,n) reaction has been successfully tested by experimental theoretical investigation of the ^{12}C(p,n)^{12}N reaction leading to the low-lying states. Spin parity assignments for higher-lying states based on the present study were consistent with those in the previous reports.

References

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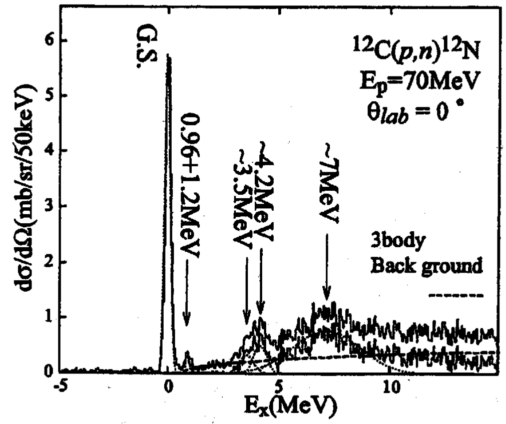

Fig. 1: Excited energy spectrum at laboratory angle 0°

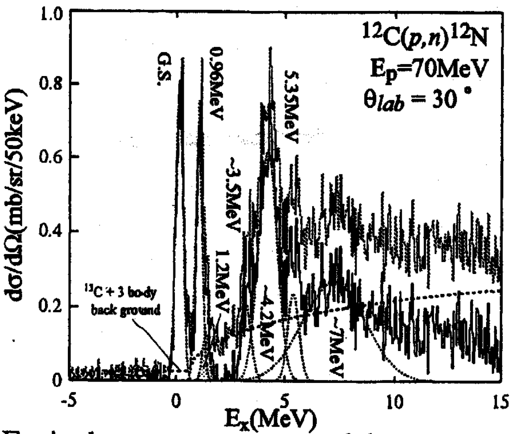

Fig. 2: Excited energy spectrum at laboratory angle 30°

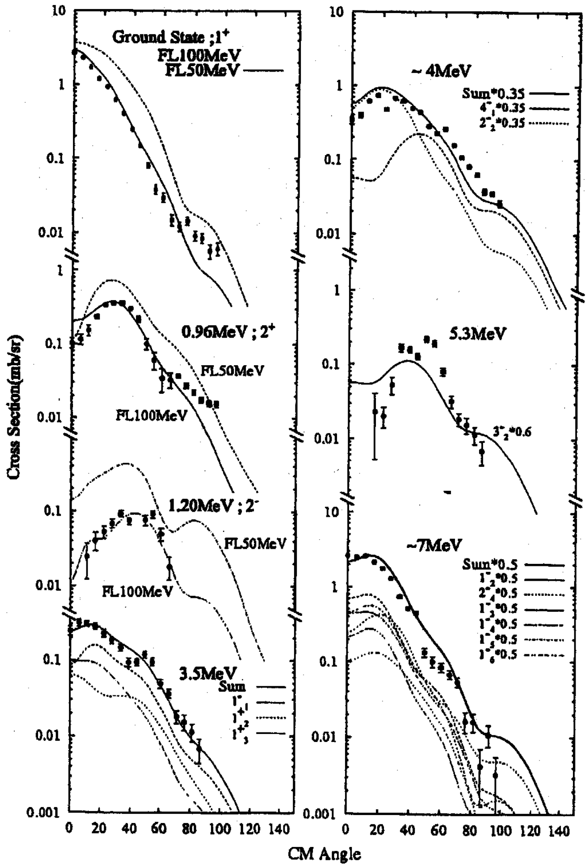

Fig. 3: Neutron angular distributions from ^{12}C$(p,n)^{12}$N reaction at E_p=70MeV.