^6Li(p,n)^6Be Reaction at E_p = 70 MeV

I. 1. ^{6}Li(p,n)^{6}Be Reaction at E_p = 70 MeV

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Because of their simple structure consisting of ^{4}He plus two nucleons, the mass 6 system provide a good place to explore the effective nucleon-nucleon interaction through, for example, charge-exchange scattering. ^{6}Li nucleus is only the odd-odd target which provides a strong $1^{+} \rightarrow 0^{+}$ GT-like transition in a pure manner for scattering experiments. A number of experiments have been reported concerning nucleon and electron scattering, as well as charge-exchange reaction on ^{6}Li[1-4]. However, there should be interesting higher excited states, for which two nucleons are excited through a different type of spin-isospin excitation.

From the view points of effective nucleon-nucleon interaction between particles or particle-hole in such a simple system, it is significant to extend scattering experiments over high-lying states whereas no reliable data have not yet reported for the transitions including to the first excited state in ^{6}Be. Petrovich and his collaborators have reported[5] consistent folding model descriptions of nucleon elastic, inelastic and charge-exchange scattering from ^{6,7}Li at 25-50 MeV.

In this report, we discuss spin-isospin excitation in nuclei through the ^{6}Li(p,n) ^{6}Be reaction by observing the transitions to the ground 0^{+} state, 1.67-MeV 2^{+} state and to the possible highly lying states. Observed neutron spectra are interpreted by particle-hole excitation and three- and four-body break up processes. Angular distributions of the differential cross section leading to the definite states are analyzed with distorted wave (DW) Born approximation, where one-body-transition-density (OBTD) has been obtained by full-space shell-model calculations.

The experiment was performed at the Cyclotron and Radioisotope Center, Tohoku

University, with a 70-MeV proton beam from the K=110MeV AVF-cyclotron and the new beam swinger system[6]. The details of the experimental setup have been described Ref. 6. Neutron energies were measured by the time-of-flight technique (TOF), where neutrons were detected by a detector array consisting of 16peaces of the disk type detector located at 44.3 m from the target. The detectors were filled with 25.1-liter organic liquid scintillator BC501A in the total sensitive volume. The absolute efficiencies of the detectors were obtained from the ^{7}Li(*p,n*) ^{7}Be activation analyses with an error less than $\pm$ 6%. Errors in the absolute magnitude of (*p,n*) cross sections were estimated to be less than 12%. The target was a metallic foil of ^{6}Li isotopes with enrichments better than 95%.

Figures 1 illustrates the neutron excitation-energy spectrum measured at a laboratory angle of 30 degree for the ^{6}Li(*p,n*)^{6}Be reaction at E_p = 70 MeV. Curves in the figure are results of the phase space calculation for three- and four-body break up, and those of peak fitting for the low-lying together with the high-laying proposed states. It is noticeable that extra states other than ground and 1.67-MeV states are seen at E_x = 3, 15 and 25 MeV as shown more clearly in the back-ground subtracted overlaid figure.

The angular distributions of neutrons for the (*p,n*) reactions leading to these five states are illustrated in Figs. 2 through 6 along with theoretical calculations. The data are compared with microscopic DW results calculated by the computer code DWBA-74[7], 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.[8] were used for the entrance channel. Those for the exit channel were potential parameters derived by Varner et al.[9] The effective nucleon-nucleon interactions used in the present DW analysis were those by Love and Franey[10]. Spectroscopic amplitudes (OBTD) for the microscopic DWBA analysis were obtained from full spsd shell model calculations using the code OXBASH[11] with the A-dependent interaction of Cohen, Kurath and Millener[12]. Single-particle radial wave functions used in DW calculations were generated in a harmonic-oscillator potential with $\alpha = 0.625$ fm^{-1}.

Figure 2 shows experimental and theoretical angular distributions of the differential cross section for the (p,n) reaction to the 0^+ ground state of ^{6}Be. Four kinds of DW calculations are shown. "pm3y(LF-100)" denotes that the (*p,n*) calculation is carried out by Love - Franey 100MeV effective interaction with OBTD obtained by the M3Y interaction in the p-shell space, while "spsd(LF-50)" corresponds to the calculation by Love

- Franey 50MeV effective interaction with OBTD by Cohen, Kurath and Millener interaction over the large spsd-shells space. The cross section magnitude at 0-degree is explained reasonably by these calculations. Over all fitting is obtained by the set of spsd(LF-100) like the case in the $^{12}C(p,n)^{12}N$ reaction as reported in Cyric Annual Report 2001 in this issue[13)]. Here after analyses are carried out by the set of spsd(LF-100) including negative parity transitions.

In Fig. 3, we present the angular distribution of neutrons leading to the 2^+ first excited state in ^{6}Be along with theoretical curves. This state is assigned to be the first 2^+ state in the shell-model prediction. There are three components in the 1^+ to 2^+ transition contributing incoherently to the cross section. The $\Delta J = 1$ component, the main part in which is $\Delta J(\Delta L, \Delta S) = 1(0,1)$ GT-transition, dominates over small angle cross section, while the $\Delta J = 3$ component does those at larger angles. An extra peak is firstly observed at $E_x \sim$ 3MeV in the (p,n) spectrum. The angular distribution in Fig. 5 shows forward peaked one suggesting an $\Delta L = 0$ transition. We tentatively assign this state to be the second 2^+ state predicted by the shell-model. Other transitions to the 1^+ and 0^+ states give much smaller theoretical cross sections. As illustrated in Fig. 4, the $\Delta J = 1$ component dominates over small angle cross section, while the $\Delta J = 2$ component does those at larger angles. Note that observed cross sections are absolutely fitted.

As seen in Fig. 1, two broad peaks have been observed at $E_x \sim$ 15 and 25MeV. These transitions are tentatively assigned to the fourth 1^-, and the fifth 2^- states predicted by the shell-model calculations. Of course, the main contribution to the continuum in the neutron spectrum in Fig. 1 is due to the ΔL=1 dipole transition[14)]. Among them, some transitions give strong intensities, thus exhibiting broad peaks, e.g. $E_x \sim$ 15 and 25MeV, as mentioned above. Comparison with theoretical predictions are shown in Figs. 5 and 6.

In a summary, the experimental study for the $^6Li(p,n)^6Be$ reaction has carried out at E_p=50 ~ 80 MeV region. Differential cross sections of neutrons leading to the five states in the residual nucleus were measured. Results have been compared with the large-space shell-model prediction based on DW theory. The newly observed low-lying state at E_x= 3MeV has been tentatively assigned to be 2^+, T=1 one. Two broad bump observed at E_x= 15 and 25MeV were discussed as 1^- and 2^- components of the ΔL=1 giant resonance. This work is supported by grant in aid for scientific research of Ministry of Education, Culture, Sports, and Science and Technology No.13640257.

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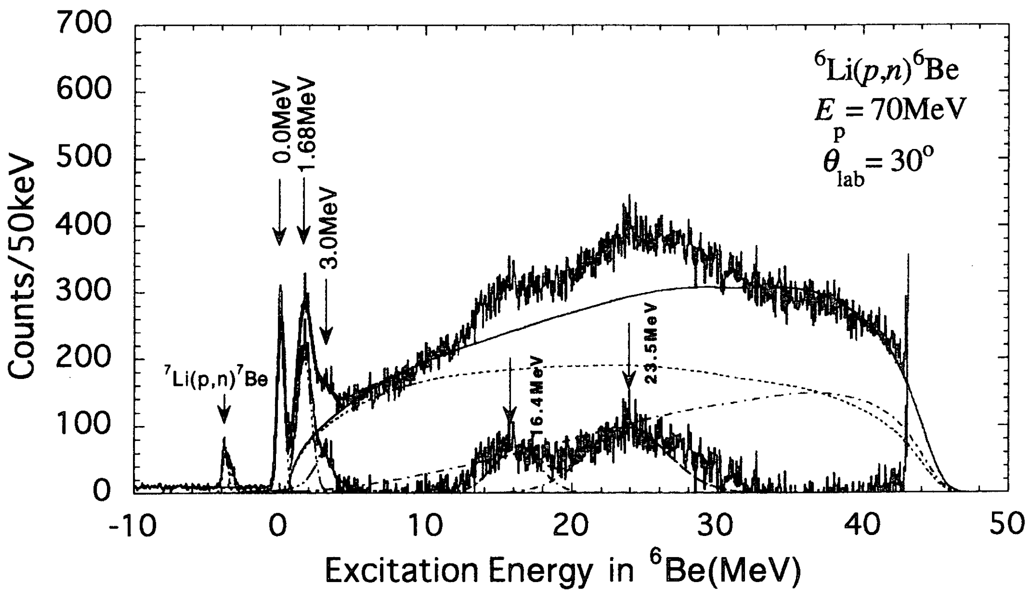

Fig. 1. A sample excitation energy spectrum from the ^{6}Li(p,n)^{6}Be reaction taken at 30° with a flight path of 44.3 m. Energy per bin is 50 keV.

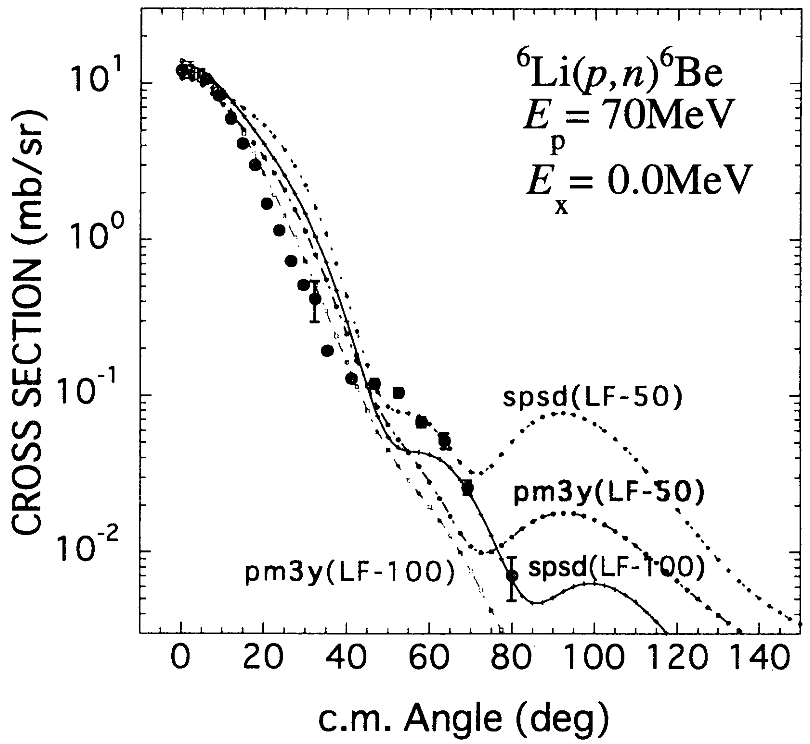

Fig. 2. Differential cross sections for neutrons leading to the ground state of ^{6}Be.

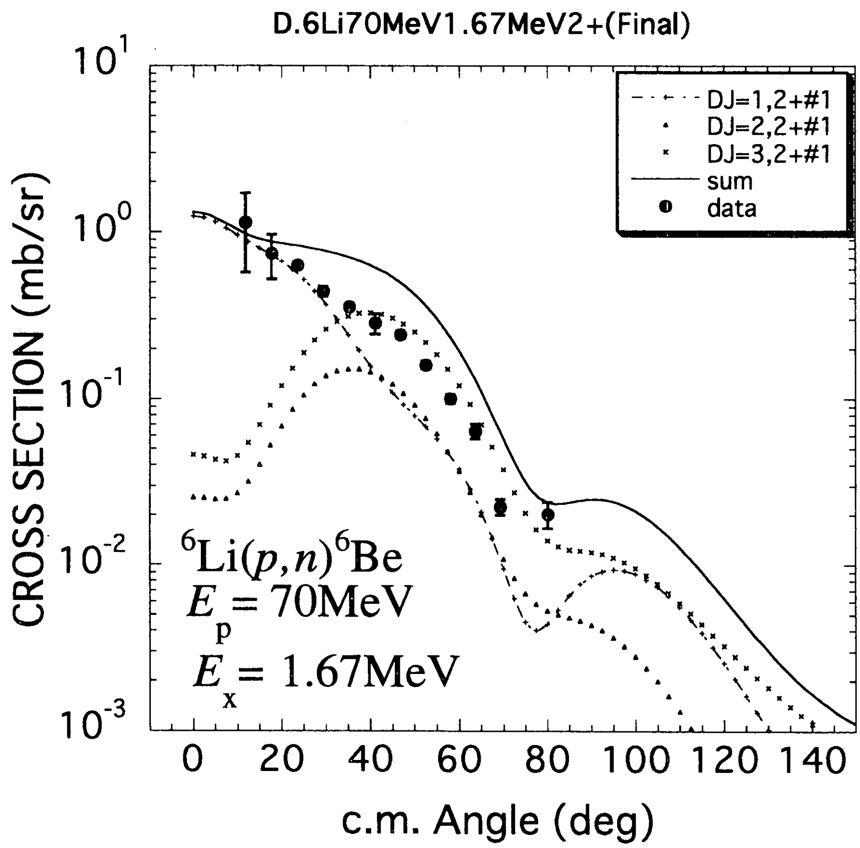

Fig. 3. Differential cross sections for neutrons leading to the 1st excited state in ^{6}Be.

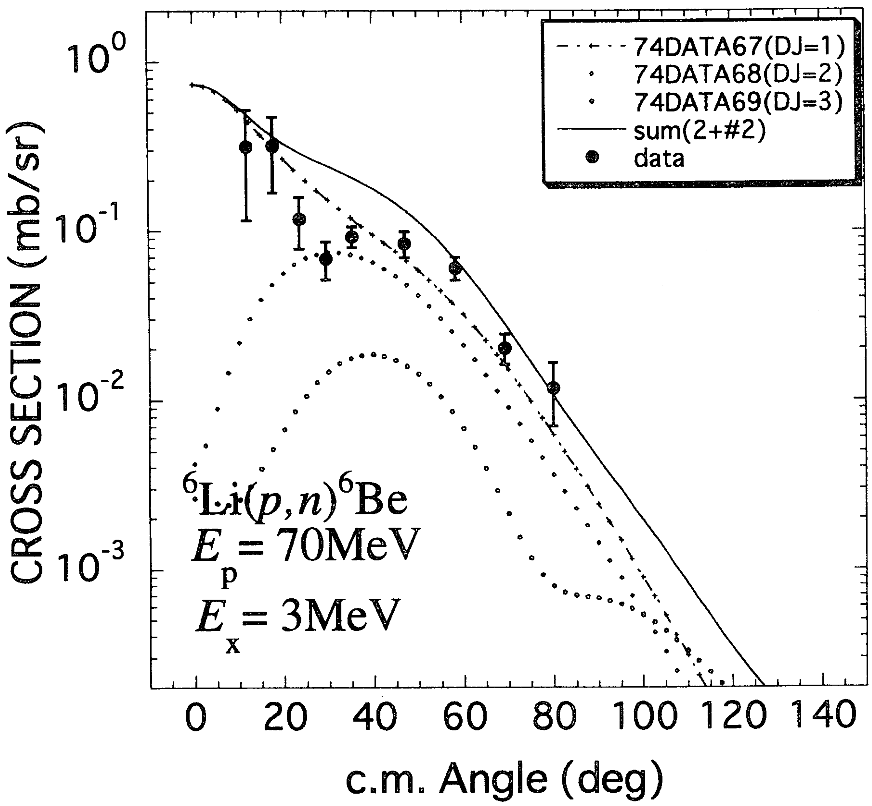

Fig. 4. Differential cross sections for neutrons leading to the excited state at E_x= 3MeV in ^{6}Be.

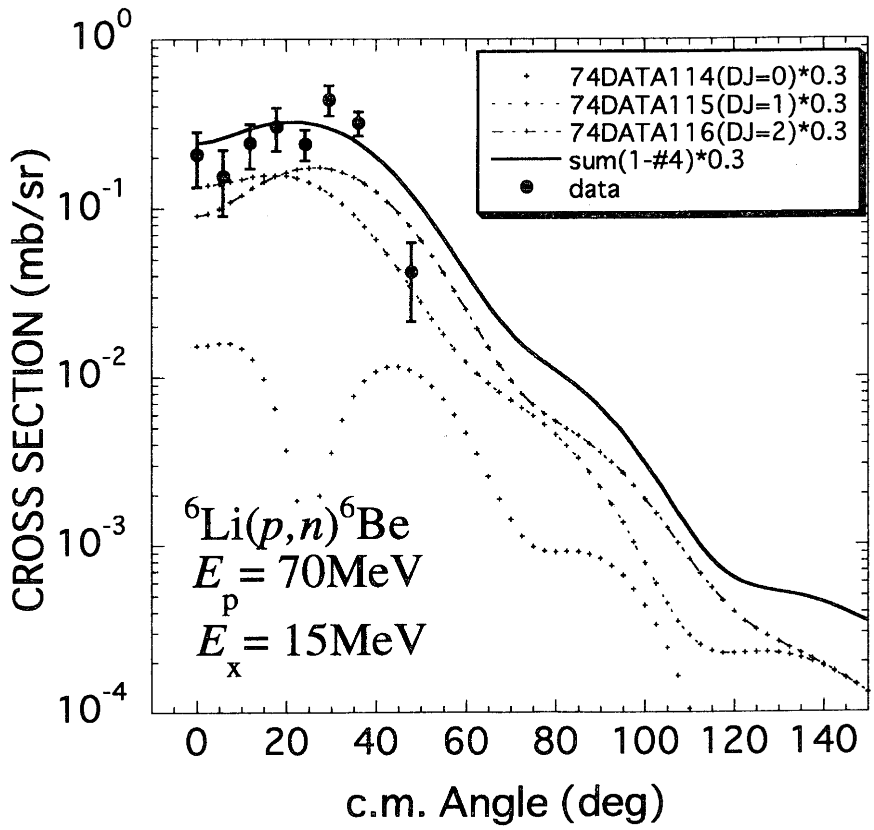

Fig. 5. Differential cross sections for neutrons leading the excited state at E_x= 15MeV in ^{6}Be..

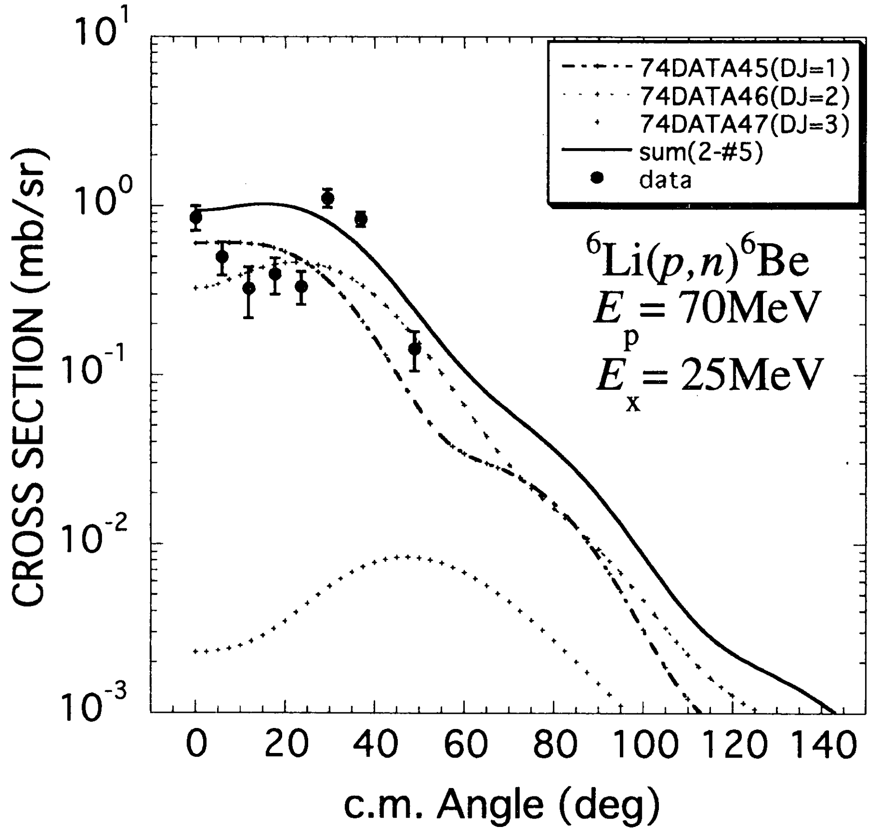

Fig. 6. Differential cross sections for neutrons leading the excited state at E_x= 25MeV in ^{6}Be..