Study of isospin excitations in nuclei via the ^6Li(p, n)^6Be reaction(Abstracts of Doctoral Dissertations,Annual Report(from April 2002 to March 2003))

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journal or publication title	The science reports of the Tohoku University. Ser. 8, Physics and astronomy
volume	24
number	1
page range	185-186
year	2003-09-29
URL	http://hdl.handle.net/10097/26177

Study of isospin excitations in nuclei via the ^{6}Li(p,n)^{6}Be reaction

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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. 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 states in ^{6}Be [1].

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 distribution of the differential cross section leading to the definite states are analyzed with distorted wave 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. The details of the experimental setup have been described in Ref. [2] . Neutron energies were measured by time-of-flight technique (TOF). The target was a 6mg/cm^2 thick metallic foil of ^{6}Li isotopes with enrichments better than 96%. Overall energy resolution better than 600keV was obtained by this setup.

Figure 1 illustrates the neutron excitation energy spectrum measured at a laboratory angle of 30° for the ^{6}Li(p,n)^{6}Be reaction at E_p=70MeV. 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 states together with those for the high-lying proposed states. It is noticeable that extra states other than ground and 1.67-MeV states are seen at around E_x~3, 15 and 25MeV as shown more clearly in the back-ground subtracted overlaid figure.

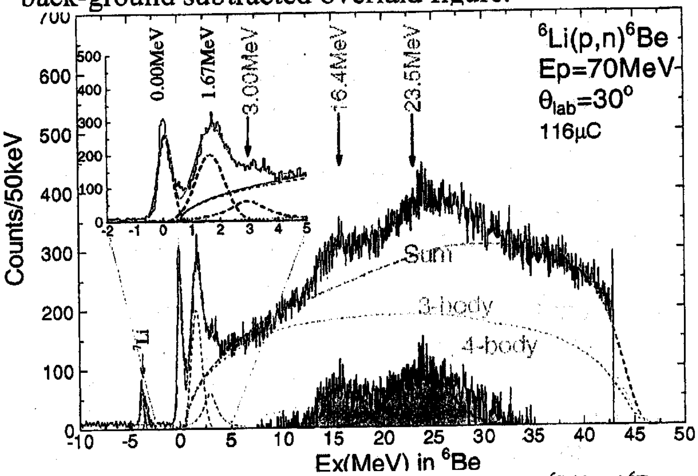

Fig. 1. Excitation energy spectrum from the ^{6}Li(p,n)^{6}Be reaction taken at laboratory angle of 30° with a flight path of 44m.

The angular distributions of neutrons for the (p,n) reactions leading to these five states are illustrated in Figure 3 along with theoretical calculations. The data are compared with microscopic DW results calculated by computer code DWBA-74 which includes knock-on exchange effects in an exact manner. Note that fully antisymmetraized 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. [3] were used for the entrance channel. Those for the exit channel were potential parameters derived by Varner et al. [4] The effective nucleon-nucleon interactions used in the present DW analysis were those by Love and Frany. Spectroscopic amplitudes(OBTD) for the microscopic DWBA analysis were obtained from full spsd shell mode calculations using the code OXBASH with the A-dependent interaction of Cohen, Kurath and Millener. Single-particle radial wave functions used in DW calculations were generated in a harmonic-oscillator potential with a

$0.625 fm^{-1}$. A theoretical (p,n) spectrum calculated by the above mentioned method is shown in Fig. 2.

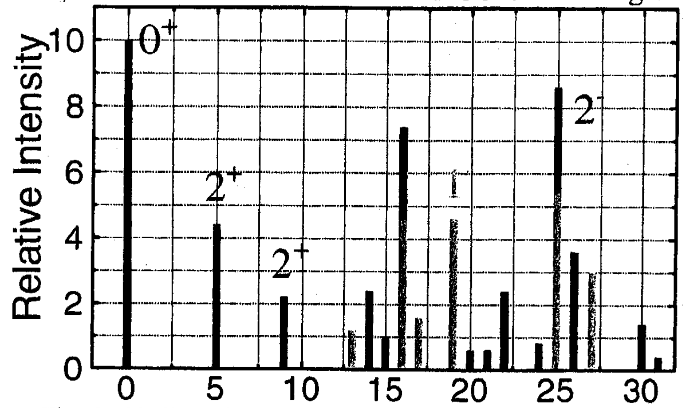

Fig. 2. Shell-model prediction of excitation energy spectrum based on DW theory. Vertical axix repre-sents relative differential cross sections at the forward angle .

Figure 3 shows experimental and theoretical angular distributions of the differential cross section for the (p,n) reaction to the observed excited states including 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-Frany 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-Frany 50MeV effec-tive interaction with OBTD by Cohen, Kurath and Mil-lener interaction over the large spsd-shells space. The cross section magnitude at 0-degree is explained reasonably well by these calculations. Overall fitting is obtained by the set of (cspsd(LF-100) henceforth analyses are carried out by this set including negative parity transitions.

In Fig. 3 labeled E_x=1.670MeV is the angular distribution of neutrons leading to the $(2)^+$ first excited state in ^{6}Be presented with theoretical curves. This state is assigned to be the first 2^+ state in the shell model prediction as seen in Fig. 2. 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~3MeV in the (p,n) spectrum. The angular distribution in Fig. 3 labeled E_x=3.0MeV shows forward peaked one suggesting an $\Delta L=0$ transition. We 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 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 around E_x~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 $\Delta L=1$ dipole transition. Among them, some transitions give strong intensities, thus exhibiting broad peaks, e.g. E_x ~ 15 and 25MeV, as mentioned above. Comparison with theoretical predictions are shown in Fig. 3 as E_x=15MeV and E_x=25MeV .

In a summary, the experimental study for the ^{6}Li(p,n)^{6}Be reaction has carried out at E_p=50-90MeV region. Differential cross sections of neutrons leading to the five states in ^{6}Be are 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 assigned to be 2^+. Two broad bump observed at E_x~15 and 25MeV were discussed as 1^- and 2^- components of the $\Delta L=1$ giant resonance.

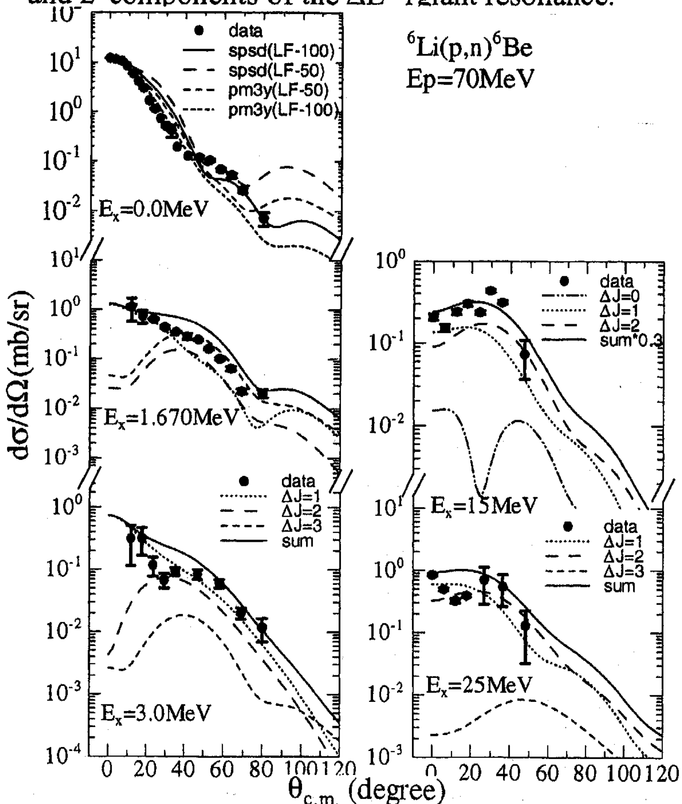

Fig. 3. Differential cross sections for neutrons leading to the observed excited states including ground state.

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