Isoscalar and Isovector M1 excitations in ^{11}B

T. Kawabata[a], H. Akimune[b], H. Fujimura[c], H. Fujita[c], Y. Fujita[d], M. Fujiwara[c], K. Hara[c], K. Hatanaka[c], T. Ishikawa[e], M. Itoh[c], J. Kamiya[c], M. Nakamura[e], H. Sakaguchi[e], Y. Shimbara[c], A. Tamii[c], T. Noro[f], H. Toyokawa[g], M. Uchida[c], H. Ueno[d], T. Wakasa[f], K. Y. Hara[b], Y. Yasuda[e], H. P. Yoshida[c], and M. Yosoi[e]

[a] *Center for Nuclear Study, Graduate School of Science, University of Tokyo*
[b] *Department of Physics, Konan University*
[c] *Research Center for Nuclear Physics, Osaka University*
[d] *Department of Physics, Osaka University*
[e] *Department of Physics, Kyoto University*
[f] *Department of Physics, Kyushu University*
[g] *Japan Synchrotron Radiation Research Institute*

Raghavan *et al.* [1] pointed out that the ^{11}B isotope can be used as a possible neutrino detector to investigate the solar-neutrino problem. High-energy neutrinos from the ^{8}B decay during the proton-proton fusion chain in the sun predominantly excite low-lying states in ^{11}B and ^{11}C by M1 and Gamow-Teller (GT) transitions via the neutral current (NC) and charged current (CC). Such neutrinos can be detected by measuring emitted electrons from the CC reaction and γ rays from the de-excitations of the low-lying states. Since there is a mirror symmetrical relation between the ^{11}B and ^{11}C and both the NC and CC reactions can be measured in the same experimental setup, the systematic uncertainty on the relative strength of the electron-neutrino flux and the entire neutrino flux from the sun is expected to be small. The precise measurement of the relative strength is indispensable to tackle the solar neutrino problem.

Since the ^{11}B nucleus has different numbers of protons and neutrons, the low-lying states in ^{11}B are excited by both the isovector and isoscalar transitions. Therefore, both the isoscalar and isovector responses must be measured to estimate the $^{11}\mathrm{B}(\nu,\nu')$ cross section. We recently measured cross sections for the $^{11}\mathrm{B}(^{3}\mathrm{He},t)$ and $^{11}\mathrm{B}(p,p')$ reactions to study the weak interaction response of ^{11}B. The cross sections of hadronic reactions provide a good measure for the weak interaction response since the relevant operators in the hadronic reactions are identical with those in β-decay and neutrino capture processes. The experiment was performed at Research Center for Nuclear Physics, Osaka University using 450-MeV ^{3}He and 392-MeV proton beams. In addition to the cross section, analyzing power, induced polarization and depolarization parameter were also measured for the $^{11}\mathrm{B}(p,p')$ reaction. Typical spectra of the $^{11}\mathrm{B}(^{3}\mathrm{He},t)$ and $^{11}\mathrm{B}(p,p')$ reactions are shown in Fig. 1.

The measured $^{11}\mathrm{B}(^{3}\mathrm{He},t)$ cross section was compared with the distorted wave born approximation (DWBA). The Cohen-Kurath wave functions (CKWFs) [2] and the Franey-Love (FL) interaction [3] were used in the DWBA calculation. Since there is a good linear proportional relation between the GT transition strength $B(GT)$ and the $(^{3}\mathrm{He},t)$ cross section at a small momentum transfer [4], we extrapolated the cross section to the zero-momentum transfer using the DWBA result and normalized by the β-decay strength from ^{11}C. The obtained $B(GT)$ values are consistent with the (p,n) result [5] within the measurement uncertainty, although the $5/2^-_1$ and $3/2^-_2$ states at $E_x = 4.32$ and 4.80 MeV were not resolved separately in the $(p,\,n)$ measurement.

The DWBA calculation using the CKWFs and FL interaction also explains the measured $^{11}\mathrm{B}(p,p')$ cross section, analyzing power, and induced polarization by introducing the scaling

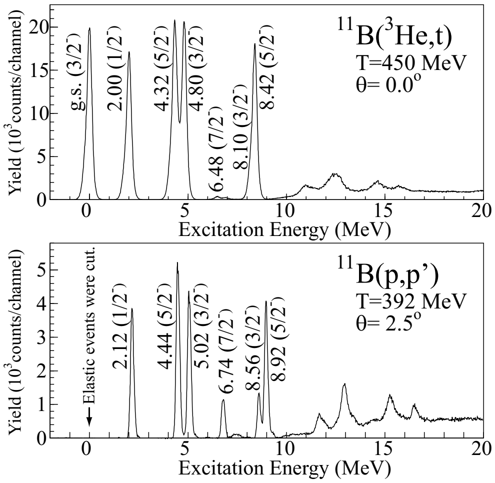

Figure 1: Spectra for ^{11}B(^{3}He, t) and ^{11}B(p, p') reactions.

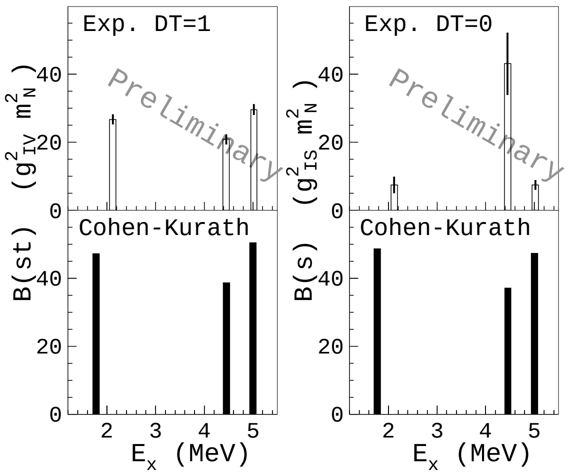

Figure 2: Measured transition matrix elements for the σ and $\sigma\tau$ operators compared with the shell model predictions.

factors for each ΔJ, but not for the depolarization parameter. To solve the problem, we performed the least-χ^2 search for the mixing ratio of the isoscalar strength to the isovector strength in the $\Delta J = 1$ and 2 transitions. The mixing parameters for $\Delta J = 1$ and 2 transitions were treated independently in the search, while the mixing parameters for other transitions are fixed as same as those from CKWFs. The reduced χ^2s are 2.17, 1.00, and 1.28 for $1/2^-_1$ at $Ex = 2.12$ MeV, $5/2^-_1$ at $E_x = 4.45$ MeV, and $3/2^-_2$ at $E_x = 5.02$ MeV, respectively. Since the reduced χ^2 for the $1/2^-_1$ state was large, an uncertainty of ± 0.01 mb/sr was artificially added to the cross section for the $1/2^-_1$ state. After that, the reduced χ^2 became 1.31. Assuming a linear proportional relation between the (p, p') cross section and transition matrix element, the matrix elements for the σ and $\sigma\tau$ operators $B(\sigma)$ and $B(\sigma\tau)$ were obtained from this search as shown in Fig. 2 with the shell model predictions. The $B(\sigma)$ and $B(\sigma\tau)$ provide the nuclear structural information required in calculations of the neutrino-nucleus cross section. It is a remarkable result that the isoscalar matrix elements $B(\sigma)$ for the $1/2^-_1$ and $3/2^-_2$ states are extremely quenched. This quenching is not predicted by the shell model predictions.

It should be noted that our result for the isoscalar strength from the (p, p') experiment has a large systematic uncertainty because the proton scattering amplitude in the M1 transition is dominated by the isovector component due to the large $|V_{\sigma\tau}/V_\sigma|$ value in the effective interaction. Thus, we plan to study the isoscalar M1 excitations in ^{11}B by measuring deuteron inelastic scattering at forward angles. Because the deuteron inelastic scattering has a selectivity for the isoscalar transition, the precise measurement of the isoscalar transition becomes possible. This experiment will be performed in summer, 2003. The result will be reported elsewhere soon.

References

[1] R.S. Raghavan, Sandip Pakvasa, and B.A. Brown, Phys. Rev. Lett. **57**, 1801 (1986).
[2] S. Cohen and D. Kurath, Nucl. Phys. 73, 1 (1965).
[3] M.A. Franey and W.G. Love, Phys. Rev. C **31**, 488 (1985).
[4] M. Fujiwara *et al.*, Nucl. Phys. **A599**, 223c (1996).
[5] T.N. Taddeucci *et al.*, Phys. Rev. C **42**, 935 (1990).