Isoscalar and Isovector spin-M1 strengths in ^{11}B

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

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

The M1 transition strengths provide important information on the nuclear structure because they could be a good measure to test theoretical nuclear models. Recently, the M1 transition strengths are of interest from a view of not only the nuclear physics but also neutrino astrophysics because the spin part of the M1 operator is identical with the relevant operators mediate neutrino induced reactions.

Raghavan *et al.* pointed out that the ^{11}B isotope can be used as a possible neutrino detector to investigate stellar processes [1]. High-energy neutrinos from the stellar processes like the proton-proton fusion chain in the sun and the supernova explosions 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) processes. 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 an isospin symmetrical relation between the ^{11}B and ^{11}C and both the NC and CC reactions can be measured simultaneously in one experimental setup, the systematic uncertainty in measuring a ratio of the electron-neutrino flux to the entire neutrino flux is expected to be small. Because there is one excess neutron in ^{11}B nucleus, the low-lying states in ^{11}B are excited by both the isovector and isoscalar transitions. Therefore, both the isoscalar and isovector spin-M1 strengths must be measured to estimate the CC and NC cross sections for the neutrino induced reactions. 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. Thus, we recently measured cross sections for the ^{11}B(^{3}He, t) and ^{11}B(d, d') reactions to determine the isovector and isoscalar spin-M1 strengths in ^{11}B.

The experiment was performed at Research Center for Nuclear Physics, Osaka University using 450-MeV ^{3}He and 200-MeV deuteron beams. The measured cross sections were shown in Figs.1 and 2. Since the ground state of ^{11}B has non zero spin, the cross sections for the ^{11}B(^{3}He, t) and ^{11}B(d, d') reactions are described by an incoherent sum over the cross section of the different multipole contributions,

$$\frac{d\sigma}{d\Omega} = \sum_{\Delta J} \frac{d\sigma}{d\Omega}(\Delta J).$$

In order to determine the spin-M1 strengths, the cross section for each ΔJ transition must be given to extract the $\Delta J = 1$ contribution.

For the ^{11}B(^{3}He, t) analysis, the cross section for the each ΔJ transition was calculated by the distorted wave impulse approximation (DWIA) as seen in Fig. 1. Since the GT strength $B(\mathrm{GT})$ for the ground-state transition is known to be 0.345 ± 0.008 from the β-decay strength, the cross sections for the $\Delta J = 1$ transitions to the excited states in

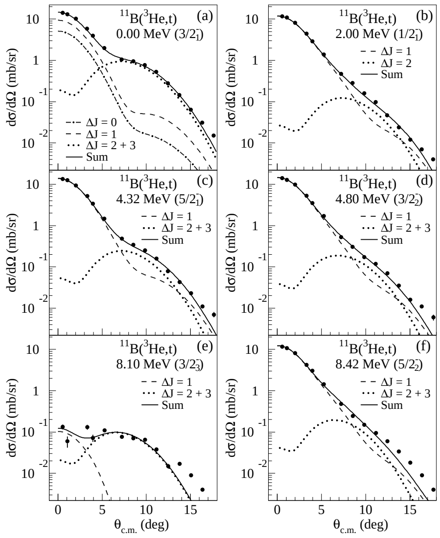

Figure 1: Cross sections for the ^{11}B(^{3}He, t) reactions compared with the DWIA calculation. The dash-dotted, dashed, and dotted curves show $\Delta J = 0$, $\Delta J = 1$, and $\Delta J \geq 2$ contributions, respectively. The solid curves are sums of the all multipole contributions.

^{11}C can be related to the $B(\mathrm{GT})$ values by assuming the linear proportional relation. The GT strengths are easily related to the isovector spin-M1 strength $B(\sigma\tau_z)$ under the assumption that the isospin symmetry is conserved. Although the isospin-symmetry breaking changes this ratio, the variation is usually small. Therefore, the GT strengths obtained from the charge exchange reaction are still useful to study the isovector spin-M1 strengths.

For the $^{11}\mathrm{B}(d,d')$ analysis, the cross section for each ΔJ transition was determined from the $^{12}\mathrm{C}(d,d')$ reaction. Since the ground state of ^{12}C has a zero spin, transitions to the discrete states in ^{12}C are expected to be good references for the angular dependence of the cross sections for certain ΔJ transitions. As shown in Fig. 2, the cross section for the $^{11}\mathrm{B}(d,d')$ reaction was successfully decomposed into the each ΔJ contributions. Although the 4.44-MeV $(5/2^-_1)$ state can be excited by both the $\Delta J^\pi = 1^+$ and 2^+ transitions, the main part of the transition is due to $\Delta J^\pi = 2^+$. This result is explained by the fact that the strong coupling between the ground and 4.44-MeV states is expected since the 4.44-MeV state is considered to be a member of the ground-state rotational band. Since the observed $\Delta J^\pi = 2^+$ transition strength is much larger than the expected $\Delta J^\pi = 1^+$ strength, the $\Delta J^\pi = 1^+$ component of the transition strength can not be reliably extracted for the 4.44-MeV state. The transition strength for the 6.74-MeV $(7/2^-_1)$ state is also dominated by the $\Delta J^\pi = 2^+$ component, but the $\Delta J^\pi = 1$ transition to this state is not allowed. The isoscalar spin-M1 strength $B(\sigma)$ for the transition to the 2.12-MeV $(1/2^-_1)$ state is 0.037 ± 0.008, which is obtained from the γ-decay widths of the mirror states and the $B(\mathrm{GT})$ value [2]. Using this value, the cross section for the $\Delta J = 1$ transitions to the other excited states can be related to the $B(\sigma)$ values. Since the $\Delta J = 1$ cross section for the 4.44-MeV state was not reliably obtained in the (d,d') analysis, the isoscalar spin-M1 strength was determined from the measured $B(\mathrm{GT})$ value and the relative strength of the isoscalar transition to the isovector transition calculated by using the Cohen-Kurath wave functions (CKWF) [3].

The obtained $B(\mathrm{GT})$ $(B(\sigma\tau_z))$ and $B(\sigma)$ values are compared with the shell model predictions using the CKWFs in Fig. 3. The CKWFs reasonably explain the experimental result except the quenching by a factor of 0.5-0.7. The present result will be useful in the measurement of the stellar neutrinos using the NC and CC reactions on ^{11}B.

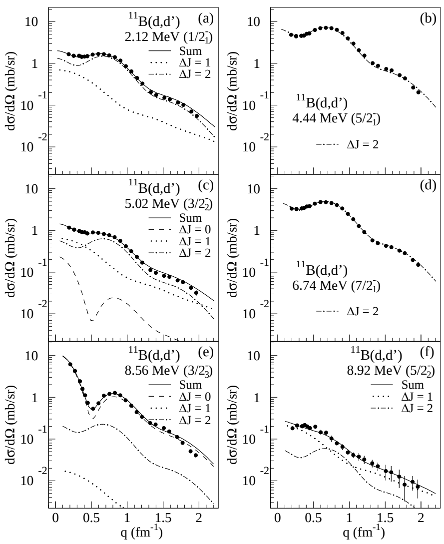

Figure 2: Cross sections for the $^{11}\mathrm{B}(d,d')$ reactions. The dashed, dotted, and dash-dotted curves show $\Delta J = 0$, 1, and 2 contributions, respectively. The solid curves are sums of the all multipole contributions.

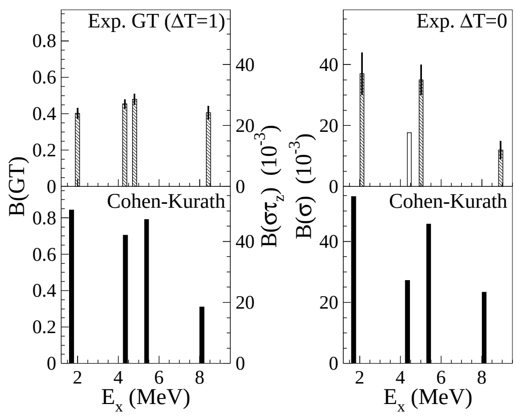

Figure 3: Measured $B(\mathrm{GT})$ $(B(\sigma\tau_z))$ and $B(\sigma)$ values are compared with the shell model predictions using the Cohen-Kurath wave functions [3]. The open bar in the right-upper panel shows the $B(\sigma)$ value for the 4.44-MeV state estimated from $B(\mathrm{GT})$ (see text).

References

[1] R.S. Raghavan, Sandip Pakvasa, and B.A. Brown, Phys. Rev. Lett. **57**, 1801 (1986).
[2] J. Bernabéu, T. E. O. Ericson, E. Hernández, and J. Ros Ncul. Phys. **B378**, 131 (1992).
[3] S. Cohen and D. Kurath, Nucl. Phys. **73**, 1 (1965).