Isoscalar and isovector spin-flip $M1$ strengths in $^{11}\text{B}$

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Abstract. The $^{11}\text{B}(^3\text{He},t)$ and $^{11}\text{B}(d,d')$ reactions were measured at forward scattering angles to study the isoscalar and isovector $M1$ strengths in $^{11}\text{B}$. Combining the experimental results from the two reactions, the excitation strengths for the isoscalar and isovector spin-flip $M1$ transitions were successfully determined for the low-lying states in $^{11}\text{B}$. The obtained strengths were compared with the shell model calculations.

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 $^{11}\text{B}$ 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 $^{11}\text{B}$ and $^{11}\text{C}$ 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 $\gamma$ rays from the de-excitations of the low-lying states. Because there is one excess neutron in $^{11}\text{B}$ nucleus, the low-lying states in $^{11}\text{B}$ are excited by both the isovector and isoscalar transitions. Therefore, both the isoscalar and isovector spin-flip $M1$ 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 probe for the weak interaction response since the relevant operators in the hadronic reactions are identical with those in $\beta$-decay and neutrino capture processes. Thus, we recently measured cross sections for the $^{11}\text{B}(^3\text{He},t)$ and $^{11}\text{B}(d,d')$ reactions to determine the isovector and isoscalar spin-flip $M1$ strengths in $^{11}\text{B}$.

The experiment was performed at Research Center for Nuclear Physics, Osaka University using 450-MeV $^3\text{He}$ and 200-MeV deuteron beams. The detailed explanations for the experimental procedures have been given in Ref. [2]. The measured cross sections were shown in Figs. 1 and 2. Since the ground state of $^{11}\text{B}$ has non zero spin, the cross sections for the $^{11}\text{B}(^3\text{He},t)$ and $^{11}\text{B}(d,d')$ reactions are described by an incoherent sum over the cross sections of the different multipole contributions as $d\sigma/d\Omega = \sum_{\Delta J^\pi} d\sigma_{\Delta J^\pi}/d\Omega(\Delta J^\pi)$. In order to determine the spin-flip $M1$ strengths by the multipole decomposition analysis, the angular distribution of the cross section for each $\Delta J^\pi$ transition must be given to extract the $\Delta J^\pi = 1^+$ contribution.

1 For the full list of authors see Ref. [2]
For the $^{11}$B$(^3$He, $t)$ analysis, the cross section for each $\Delta J^\pi$ transition was calculated by using the distorted wave impulse approximation as shown in Fig. 1. Since the GT strength $B(\text{GT})$ for the ground-state transition is known to be $0.345 \pm 0.008$ from the $\beta$-decay strength, the cross sections for the $\Delta J^\pi = 1^+$ transitions to the excited states in $^{11}$C can be related to the $B(\text{GT})$ values by assuming the linear proportional relation. The GT strengths are easily related to the isovector spin-flip $M1$ 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-flip $M1$ strengths.

![Figure 1](image1.png)  
**Figure 1.** Cross sections for the $^{11}$B$(^3$He, $t)$ reactions.  

![Figure 2](image2.png)  
**Figure 2.** Cross sections for the $^{11}$B$(d, d')$ reactions.

For the $^{11}$B$(d, d')$ analysis, the cross section for each $\Delta J^\pi$ transition was calculated by using the deformed potential method. As shown in Fig. 2, the cross section for the $^{11}$B$(d, d')$ reaction was successfully explained by the calculation. The isoscalar spin-flip $M1$ strength $B(\sigma)$ for the transition to the 2.12-MeV ($1/2_1^-$) state is $0.037 \pm 0.008$, which is obtained from the $\gamma$-decay widths of the mirror states and the $B(\text{GT})$ value [3]. Using this value, the cross section for the $\Delta J^\pi = 1^+$ transitions to the other excited states except the $5/2_1^-$ state at $E_x = 4.44$ MeV can be related to the $B(\sigma)$ values. Since the observed $\Delta J^\pi = 2^+$ transition strength for the 4.44-MeV state 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. Thus, the isoscalar spin-flip $M1$ strength for this state was determined from the measured $B(\text{GT})$ value and the relative strength of the isoscalar transition to the isovector transition calculated by using the Cohen-Kurath wave functions (CKWF) [4].

The obtained $B(\text{GT}) (B(\sigma \tau_z))$ 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.

**References**

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