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Extraction of 2^+ component from spin-polarization observables

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Recently, some groups studied about ^{6}Li(d,α) reaction near zero energy for astrophysical interests. The reaction is affected by an 2^+ resonant level below the reaction threshold. In this work, we measured the analyzing powers for this reaction at an very low incident energy and extracted 2^+ component.

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Nuclear reaction at extremely low energies is an important subject in astrophysics as the mechanism of producing elements in universe. Recently, ^{6}Li/^{7}Li abundance ratio is thought of as a key to investigate the baryon density, and ^{6}Li+d reactions can play an important role for destruction of ^{6}Li when the inhomogeneous big bang nucleosynthesis is assumed, because the inhomogeneous models assume a fluctuation of baryon density and deuteron induced reactions can play a important role. Generally, cross sections of the reactions between charged particles decrease exponentially when the incident energy decreases because of the Coulomb barrier. When cross-section data are not available at a given energy due to the smallness of the cross section or the uncertainty of the electron screening effect, one should extrapolate the data in a high energy region. In the case of ^{6}Li+d reactions at low energies, the reaction cross sections are affected by the 2^+ resonance level of ^{8}Be at $E_x \simeq 22.2$ MeV, with the 800 keV width located at 80 keV below the reaction threshold, and the estimation of the resonance effect for the reaction is important for the extrapolation process [1].

In this work, we used analyzing powers to evaluate the resonance effect. Analyzing powers are quantities associated with the beam-spin polarization of the incident particle. Angular distribution of the analyzing powers are sensitive to the information of the resonance level. For ^{6}Li(d,α)^{4}He reaction at a low incident energy, by using the invariant amplitude method (IMA) [2], the analyzing powers are represented as

$$iT_{11} = 0, \tag{1}$$

$$T_{2q} = -\frac{1}{\sqrt{5}} f P_{2q}(\cos\theta), \quad (q = 0,1,2) \tag{2}$$

where P_{2q} is Legendre function. In the derivation of above expressions, the angular momentum of initial channel is restricted to 0. The detail of the derivation is written in Ref. [3]. The coefficient f is represented by using the invariant amplitude F as

$$f = \frac{|F(2020)|^2 - 2\sqrt{2}\mathrm{Re}\{F^*(0000)F(2020)\}}{|F(0000)|^2 + |F(2020)|^2}. \tag{3}$$

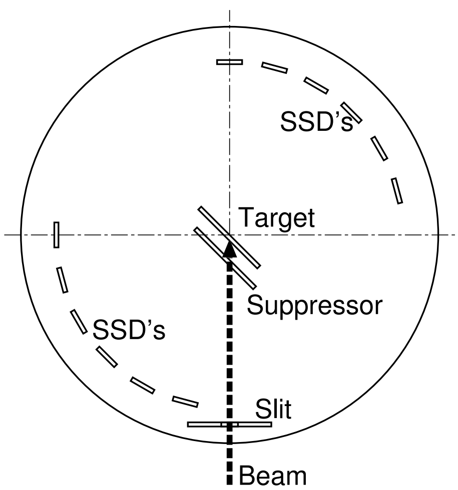

Figure 1: Layout of detectors and target in the scattering chamber.

The invariant amplitude F is described as

$$F = F(s_i, s_f, K, l_i)$$

where s_i and s_f are initial and final channel spin, K is the rank of spin-space tensor, l_i is the orbital angular momentum of initial channel. $|F(2020)|^2$ and $|F(0000)|^2$ describes the $s = 2$ and $s = 0$ component of the cross section, where s is total spin of the reaction. By using the coefficient f, we can evaluate the fraction of the 2^+ component of the cross section as

$$f_{2^+} = \frac{|F(2020)|^2}{|F(2020)|^2 + |F(0000)|^2} \tag{4}$$

$$\simeq \left\{1 + \frac{1}{8}(1-f)^2\right\}^{-1}. \tag{5}$$

The experiment was performed at the University of Tsukuba Tandem Accelerator Center (UT-TAC) using the Lamb shift-type polarization ion source [4] at the incident energy of 90 keV. The polarization of the deuteron beam was measured by the quench-ratio method [5] about every two hours. The typical value of the beam intensity was about 100 nA, and that of the beam polarization was about 0.70. The uncertainty of the polarization was about 0.02. Figure 1 shows the placement of the detectors and the target. The target was a layer of lithium carbonate, Li_2CO_3, having a thickness of about 10 μg/cm^2 on an aluminum backing having a thickness of about 15 μm. The enrichment of ^{6}Li was 95%. The beam was introduced to the lithium carbonate layer and was intercepted by the aluminum backing, which played the role of a Faraday cup. A slit with a diameter of 5 mm was placed at a distance of 150 mm upstream from the target. The energy loss in the layer

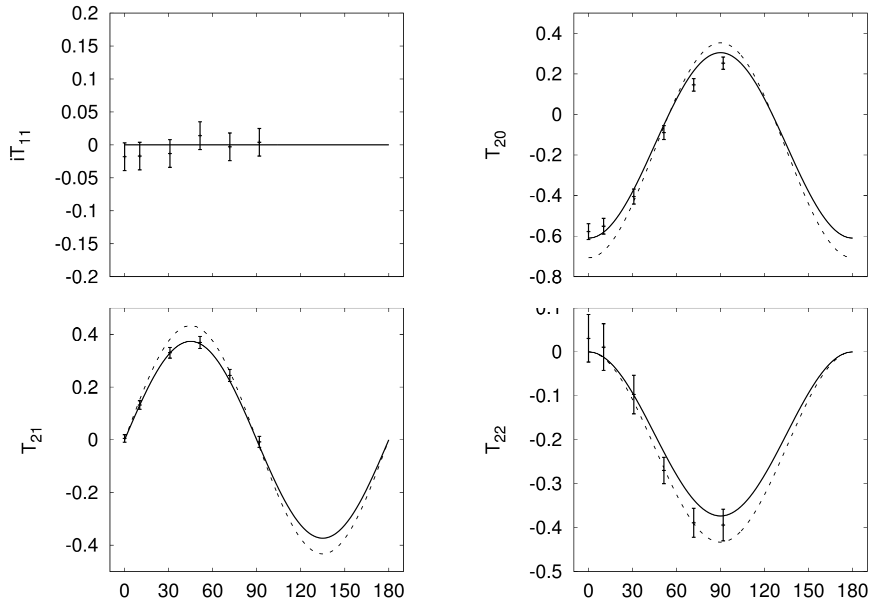

Figure 2: Experimental results for ^{6}Li(d, α)^{4}He. The dashed curve represents the prediction when $f = f_{2^+} = 1$. The solid curve is the fitting result ($f = 0.86$)

of lithium carbonate was about 8 keV. We placed six Si-SSD's around the target from the scattering angle 0° to 90°. Each detector was placed at a distance of 140 mm from the target, and had a solid angle of 10 msr. On each Si-SSD placed in the range of scattering angles from 90° to 165°, a mylar sheet having a thickness of 9 μm was placed in order to block elastic deuterons.

The experimental result was well explained by above Equations as shown in Fig. 2. The dashed line represents the one for $f_{2^+} = 1$. The solid one is fitting result. The deduced value is $f = 0.862 \pm 0.087$. It corresponds the value $f_{2^+} = 0.998 \pm 0.003$. This means that the reaction almost goes through the total spin of 2^+, which is the same spin parity as the sub-threshold resonance of ^{8}Be.

We also examined the analyzing powers for the (d,α) reaction by zero-range DWBA analysis used in Ref [1], but including a deuteron LS interaction which was neglected in Ref [1]. At present, we have not yet obtained successful results, although many parameter sets of the optical potentials have been examined; the results of DWBA analysis tend to be proportional to $(-)^q P_{2q}$ $(q = 0, 1, 2)$ while the experimental data $T_{2q}(\theta)$ are proportional to the Legendre function P_{2q}.

These results indicate that the direct reaction component is negligibly small and the resonant component is dominant. This is inconsistent with the Ref [1], in which the direct reaction component and resonant one are in the same degree at the incident energy of 90 keV.

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