Triton and Helion Transfer in the $^{10}\text{B}(\alpha, ^7\text{Li})^7\text{Be}$ Reaction at $E_{\text{lab}}=91.8$ MeV

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Angular distributions of the $^{10}\text{B}(\alpha, ^7\text{Li})^7\text{Be}$ reaction were measured at $E_{\text{lab}}=91.8$ MeV in the entire center of mass angular region. A DWBA analysis explains the reaction as triton and helion transfer in the forward and backward angular regions, respectively.

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1. Introduction

The nuclear reactions with the $^7\text{Li}$ or $^7\text{Be}$ nuclei in the final state attracted attention since Barshay and Temmer [1] formulated a theorem which provides a simple test of the isospin multiplet nature of analog states. In a $^{10}\text{B}(\alpha, ^7\text{Li})^7\text{Be}$ experiment at $E_{\text{lab}}=46$ MeV [2] it was shown that with good approximation the ground states of $^7\text{Li}$ and $^7\text{Be}$ constitute an isospin doublet and the interaction involved in this reaction is charge independent, i.e., it conserves isospin. This conclusion was based on the comparison of the magnitudes of the cross sections in backward and forward angular regions without any attempt to perform an analysis investigating the reaction mechanism. However, as it was pointed out in Ref. 3, the sequential two-stage processes proceeding e.g. through isospin mixed states of intermediate nuclei could introduce the isospin impurity.

The aim of the present experiment is to investigate this reaction at such a high energy, that the dominance of direct reaction mechanism will be ensured and so it could be tested to what extent the triton or $^3\text{He}$ transfer could account for the observed angular distribution.

2. Experimental Procedure

The experiment was performed using the $\alpha$-particle beam of $E_{\text{lab}}=91.8$ MeV from the cyclotron JULIC

Fig. 1. Particle identification in the two-dimensional $\Delta E$ vs. $E$ spectrum

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of the Kernforschungsanlage Jülich. The $^{10}$B target with an enrichment of 96.35% and 60 µg/cm² thickness had been evaporated on a 20 µg/cm² $^{12}$C backing. The target thickness was determined by measurement of the energy loss of α-particles from a $^{244}$Cm source.

The outgoing reaction products $^7$Li, $^7$Be as well as elastically scattered particles were momentum analyzed in the QOOGQ magnet spectrometer BIG KARL [4]. The beam line was set up in the high intensity mode matched to the spectrometer dispersion $D = 13.6$ m. The particle position in the focal plane was measured with two multi-wire proportional chambers (MWPC) with delay line read-out [5]. For particle identification a $\Delta E$ gas detector and an $E$-plastic scintillation counter were used [5]. The spectra were measured for Li and Be identified by events in appropriate regions of two dimensional $\Delta E$ vs. $E$ spectra (Fig. 1). The magnetic fields were adjusted in order to compensate the kinematic factors and obtain a good momentum resolution for the solid angle of the spectrometer (up to 1.6 msr). The obtained resolution was sufficient to resolve the first excited states of $^7$Li or $^7$Be from the ground states leaving, however, unresolved peaks corresponding to the first excited states at 0.478 MeV in $^7$Li and 0.429 MeV in $^7$Be. Examples of spectra are shown in Fig. 2. As can be seen, transitions leading to simultaneous excitation of the first excited states in both $^7$Li and $^7$Be could be observed with very small cross sections.

The measurements were performed from $\theta_{lab} = 8^\circ$ to $32^\circ$ in $2^\circ$ steps for both $^7$Li and $^7$Be particles. The elastic scattering of α-particles was measured from $\theta_{lab} = 7^\circ$ to $55^\circ$ in $2^\circ$ steps. The relative differential cross sections at different angles were obtained by normalizing the observed number of counts with the corresponding beam charge measured in the Faraday cup. The normalization of the cross section was determined from the measured thickness of the target, the acceptance solid angle of the spectrometer and beam current calibration. This normalization was checked in a separate measurement using a $\Delta E - E$ semiconductor counter telescope in a scatter-

Fig. 2. The momentum spectra of $^7$Li and $^7$Be particles from the $^{10}$B($^7$Li,$^7$Be)$^7$Be reaction at $E_{lab}=91.8$ MeV.

Fig. 3. Angular distributions for the $^{10}$B($^7$Li,$^7$Be)$^7$Be reaction leading to the ground state and first excited states of the final nuclei. The curves give the results of DWBA calculations with set A (solid line) or set B (dashed line) of optical model parameters in the entrance $\alpha$-$^{10}$B channel.
The angular distribution of $\alpha$-particles scattered elastically from $^{10}\text{B}$ at energies 40 MeV, 50.6 MeV (Ref. 6) and 91.8 MeV (present experiment). Solid and dashed lines show results of optical model calculations with parameter set A and B, respectively.

3. Analysis

The ratio of cross sections at corresponding angles in the forward and backward hemisphere averages to $1.09 \pm 0.09$ and $1.03 \pm 0.16$ for the transitions to the ground and to the first excited states, respectively, in excellent agreement with the Barshay and Temmer theorem. In order to investigate the mechanism of the reaction a DWBA analysis was performed. The exact finite range program Jupiter-5 written by T. Tamura and T. Udagawa according to the formalism of [7] and modified by B. Kamys et al. [8] was used.

The binding potential of the transferred particle to the core was assumed to be of Wood-Saxon form with the geometrical parameters $R=0.85 \ (A_{1}^{1/3} + A_{2}^{1/3})$ fm, $a=0.65$ fm, while the depth was adjusted to obtain the proper binding energy. Such parametrization leads for the three- or four-nucleon clusters forming $^7\text{Li}$ and $^7\text{Be}$ to the mean square separation of $R^2=13.8$ fm$^2$ in accordance with the value $(13.5 \pm 0.3)$ fm$^2$ determined by Buck [9] from the charge radius, quadrupole moments and $B(E2)$ values.

The optical model parameters in the $\alpha+^{10}\text{B}$ entrance channel were obtained from the optical model analysis of the elastic scattering data at $E_{lab}=40$ MeV, 50.6 MeV [6] and 91.8 MeV (present experiment). The following analytical expression of the potential was used with a linear energy dependence of the absorption:

$$U(R) = V \left(1 + \exp \frac{r-R_{V}}{a_{V}}\right)^{-1} + i(W_{0} + W_{1} \cdot E_{c.m.}) \left(1 + \exp \frac{r-R_{W}}{a_{W}}\right)^{-1}\ R_{j} = \eta_{j} (A_{1}^{1/3} + A_{2}^{1/3})\ j = (U, W).$$

The search for the best fit parameters led to two families denoted A and B in Table I. The quality of obtained fits can be seen from Fig. 4, where the results of the calculations are compared with the experimental data. As no experimental data exist for the elastic scattering of $^7\text{Li}$ on $^7\text{Be}$ the interaction in the exit channel was approximated by the optical model potential for the $^7\text{Li}+^9\text{Be}$ system determined in Ref. 10 from the analysis of elastic scattering data at $E_{c.m.}=19.12$ MeV. However, since this energy differs considerably from the $E_{c.m.}=49.3$ MeV in the exit channel of the present experiment an energy dependence of the imaginary part was introduced in this potential. The parameters $W_{0}$ and $W_{1}$ were then determined by reproducing the $\alpha$-transfer data in the $^{11}\text{B}(^{3}\text{He},^{7}\text{Be})^{7}\text{Li}$ reaction investigated in Ref. 11. The parameters of this potential are also given in Table I. It should be mentioned that such a dependence of the absorption on the energy led to the prediction of a physically reasonable energy dependence of the Li+Be elastic scattering while the potential without this dependence gives a rather unrealistic increase of cross sections at larger angles. Spectroscopic amplitudes needed in this calculation...
Table 1. Optical model parameters

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<th>System</th>
<th>$V$ (MeV)</th>
<th>$r_V$ (fm)</th>
<th>$a_V$ (fm)</th>
<th>$W_\sigma$ (MeV)</th>
<th>$W_\ell$</th>
<th>$r_\ell$ (fm)</th>
<th>$a_\ell$ (fm)</th>
<th>$r_c$ (fm)</th>
<th>Potential set</th>
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<td>$\alpha + ^{10}\text{B}$</td>
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<td>154.73</td>
<td>0.843</td>
<td>0.603</td>
<td>3.458</td>
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<td>0.848</td>
<td>0.806</td>
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<td>0.780</td>
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Table 2. Spectroscopic amplitudes

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<th>$l$</th>
<th>$j$</th>
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<td>$5/2$</td>
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<td>3</td>
<td>$7/2$</td>
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<td>$^4\text{He}$</td>
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4. Discussion

The results of the measured differential cross section for the $^{10}\text{B}(\alpha, ^7\text{Li})^7\text{Be}$ reaction leading both to the ground states and the first excited states of the final nuclei were compared with DWBA calculations for three-nucleon cluster transfers. The calculation was performed without adjustable parameters. For the interaction in the entrance channel, the comparison with the experiment favours distinctly set $A$ of the optical model parameters resulting from the analysis of experimental $\alpha + ^{10}\text{B}$ elastic scattering data. The satisfactory agreement of DWBA calculations with experimental data at $E_{\text{lab}} = 46$ MeV and 91.8 MeV justifies the linear energy dependence of the imaginary part of optical potentials in the entrance and exit channels established by the analysis of elastic scattering and the $^{11}\text{B} (^3\text{He}, ^7\text{Be})^7\text{Li}$ reaction [11].

The one-step triton- and helium-cluster transfers considered in the performed DWBA calculations account well for the measured cross sections. This indicates the dominance of the single-step processes in the reaction. Such a reaction mechanism evidently conserves isospin leading to the $90^\circ$ symmetry of the cross section in full accord with the Barshay-Temmer theorem.

References

L. Jarczyk et al.: $^\text{16}\text{B}(\alpha, ^\text{7}\text{Li})^\text{Be}$ Reaction at $E_{\text{lab}} = 91.8$ MeV


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