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MEASUREMENTS OF DIFFERENTIAL CROSS SECTIONS

FOR THE REACTIONS $^{6,7}\text{LI(N, D)}^{5,6}\text{HE AND} \,^{6,7}\text{LI(N, T)}^{4,5}\text{HE AT 14.1 MEV}$

August 1989

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日本原子力研究所 Japan Atomic Energy Research Institute

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Measurements of Differential Cross Sections for the Reactions 6,7 Li(n,d) 5,6 He and 6,7 Li(n,t) 4,5 He at 14.1 MeV

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A summary of our measured cross sections for the 14.1 MeV neutroninduced reactions on lithium isotopes has been presented. Our data were measured with two counter telescopes, each of which consisted of two gas proportional counters and silicon ΔE and E detectors. Measured energy spectra of deuterons and tritons from ⁶Li(n,d)n⁴He and ⁷Li(n,t)n⁴He, respectively, were analyzed by a simple final-state interaction theory. Measured angular distributions for these reactions as well as ⁶Li(n,t)⁴He and ⁷Li(n,d)⁶He were analyzed by exact finite-range distorted wave Born approximation (EFR-DWBA) calculations. Spectroscopic factors extracted from the EFR-DWBA analyses have been compared with theoretical predictions.

Keywords: Neutron Nuclear Data, $E_n = 14.1 \text{ MeV}$; ⁶Li and ⁷Li, Enriched Target; Measured $\sigma(\theta, E)$ and $\sigma(\theta)$; DWBA, Spectroscopic Factor

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14.1 MeV での反応^{6,7}Li(n,d)^{5,6}Heと ^{6,7}Li(n,t)^{4,5}Heの微分断面積の測定

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(1989年7月21日受理)

リチウム同位体に関する 14.1 MeV 中性子 誘起核反応断面積の測定結果についてまとめた。われわれのデータは二つのカウンターテレスコープを用いて得られた。このテレスコープは2個の ガス比例計数管とシリコン 4 E と E 検出器からなっている。⁶ Li(n,d)n⁴ He と¹ Li(n,t)n⁴ He からのそれぞれ重陽子と三重陽子の測定されたエネルギースペクトルは簡単な終状態相互作用理 論によって解析された。これらの反応および⁶ Li(n,t)⁴ He と¹ Li(n,d)⁶ He の測定された角分 布は、正確な有限レンジひずみ波 Born 近似(EFR-DWBA)計算によって解析された。 EFR-DWBA 解析から導かれた分光学的因子は理論計算と比較されている。

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1. Introduction

Experimental data on the fast-neutron induced reactions for the emission of charged particles from lithium isotopes 6,7 Li are very important to investigate not only the reaction mechanism and the cluster structure in nuclear physics but also the fusion reactor in nuclear engineering. However, the data and analyses of absolute cross sections for these reactions are very scarce even at the present time.

Previously, we measured the differential cross sections for the reactions ${}^{6}Li(n,d){}^{5}He$ and ${}^{6}Li(n,t){}^{4}He$ at 14.1 MeV in a limited angular region and compared our data with the calculations of exact finite-range distorted wave Born approximation (EFR-DWBA)¹⁾. Since then. we have continued to obtain the absolute cross section data not only on ${}^{6}\text{Li}^{2,3}$ in a wider angular region but also on $7_{\text{Li}4,5,6}$. As mentioned in a previous paper⁵⁾, some discrepancies between experimental data and EFR-DWBA calculations were found at some angles. A remeasurement $^{6)}$ was required to obtain more accurate energy spectra of tritons and deuterons especially from ⁷Li bombarded by 14.1 MeV neutrons. As the result of these efforts, it was found that our data were in fairly well agreement with the data of Zagreb group $^{7-10)}$ using 14.4 MeV neutrons in some angular ranges and generally could be reproduced to some extent over measured angular ranges by EFR-DWBA calculations, yielding information about spectroscopic factors on the basis of the particle pickup mechanism.

In this paper, we present a summary of our experimental data¹⁻⁶⁾ on the one- or two-nucleon transfer reactions for 6,7 Li, comparing with the Zagreb data of 14.4 MeV in some figures as well as with the EFR-DWBA predictions to derive spectroscopic factors. In sect. 2, we also

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describe the details of our newly performed experiment⁶⁾, in which we aimed to settle the 7 Li(n,d)⁶He data of relatively small cross sections (less than 1 mb/sr).

2. Experimental procedures

The procedures of our series experiments using 95.58% enriched ⁶Li metal targets of various thicknesses ranged from 2.35 to 3.74 mg/cm^2 and a preliminary one using a 12.44 mg/cm² natural lithium metal target have been reported in a previously published paper¹) and unpublished ones^{2,3,4}). These experiments have been performed using an old 200 kV Cockcroft-Walton accelerator of Rikkyo University. As mentioned in sect. 1, here we describe only our most recent experiment on ⁷Li using a newly constructed 300 kV Cockcroft-Walton accelerator¹¹ for the production of the ³H-d neutrons of 14.1 MeV.

The absolute determination of neutron yields in this experiment was performed with an accuracy of about 2% by use of the associated α -particle method using a Si p-i-n photodiode (Hamamatsu S1723-06) as the α -monitor and a ³H-Ti-Cu target (Amersham TRT-31, 2.4 Ci). The details of this method have been described elsewhere¹¹⁾. Another Si p-i-n photodiode (Hamamatsu S1722) and a NE213 liquid scintillator, which were placed at 3 cm and 100 cm respectively from the neutron source point, were employed as neutron monitors. An accelerated deuteron beam of 170 keV was collimated by passing through two collimators of 3 mm and 2 mm in diameter after focusing by Q-magnets.

A 3.90 \pm 0.06 mg/cm² target of 99.988% enriched ⁷Li metal was prepared by rolling⁶ and placed on the upper hole of a target holder (Al or Ta) with two holes of 5.9 mm in diameter. This target was placed

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3.0 cm from the neutron source point at the center of a scattering chamber¹²⁾. In the chamber, two counter telescopes (CT1 and CT2) were placed 4.6 cm from the lithium target. A collimator of 5 mm in diameter was located in front of the ΔE detector of each counter telescope for defining the solid angle, as seen in fig. 1. Each counter telescope consisted of two gas proportional counters and silicon ΔE and E detectors. The counter gas of Ar with 5% of CO₂ was filled to a pressure of 100 Torr in the chamber. The experimental arrangement as well as the thicknesses of the silicon ΔE and E detectors is shown schematically in fig. 1.

A block diagram of the electronic system used in this experiment is shown in fig. 2. Energy and time signals from eight detectors, viz. two counters (PC₁₁, PC₁₂) and 32 μm and 1500 μm Si detectors (Si ΔE_1 , SiE₁) for CT1, and two counters (PC₂₁, PC₂₂) and 16 μm and 1500 μm Si detectors $(Si\Delta E_2, SiE_2)$ for CT2, were taken as list mode data on magnetic tape by a CAMAC data acquisition system, after being treated by a NIMmodule electronic system. The multiparameter event data were analyzed in real-time for particle identification, and the energy spectra of separated charged particles (p, d, t and ⁴He) were obtained in the off-The particle identification was almost completely line analysis. performed, as seen in fig. 3-a (with target) and -b (without target) for the telescope setting angle $\theta_0 = 0^\circ$ and also in fig. 3-c (with target) and -d (without target) for $\theta_0 = 50^\circ$, which illustrated the typical examples of a plot of energy E vs energy loss ΔE .

In our series experiments, the absolute cross sections for ${}^{6}Li$ have been determined with overall accuracies of about $\pm 5 - 11\%$ for the (n,d) case and $\pm 7 - 14\%$ for the (n,t) case in the measured angular range from 0° to 130° . These uncertainties include the systematic error originated

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from the uncertainties in target thickness $(\pm 1 - 3\%)$, geometry $(\pm 3\%)$ and neutron flux $(\pm 2\%)$. The absolute cross sections for ⁷Li were determined with the statistical errors of about $\pm 4 - 32\%$ for (n,t) and of about $\pm 40\%$ for (n,d) in the measured angular range from 0° to 80° . These data on ⁷Li do not include the systematic error mentioned above.

3. Results and discussion

The energy spectra of deuterons and tritons from the reactions 6 Li(n,d)⁵He and 7 Li(n,t)⁵He, respectively, were measured at various telescope setting angles in the ranges from 0° to 130° for ⁶Li and to 80° for 'Li. These experimental data for the final three-particle reactions are tabulated in the appendix (tables A1 and A2). Typical examples of the measured energy spectra are shown in fig. 4. The energy spectrum observed at a forward angle shows a remarkable peak due to the final state interaction (FSI) especially at the high energy end, as seen in The curves drawn in fig. 4 are the results of calculations fig. 4. taking into account n- α , n-t and t- α FSIs, which are represented by the phase-shifts δ^{2J}_{L} of L-wave scattering in the unobserved pair subsystem of total angular momentum J in the final state. An energy resolution of 800 keV has been folded into the curves of fig. 4. Both the deuteronand the triton-energy spectra are dominated by the FSI effects of the well-known $P_{3/2}$ n- α scattering at the high energy end. In this energy region, the Lehman effect of the n- α plane-wave final-state component¹³⁾ does not appear to be significant. In the case of the triton energy spectrum, the significant enhancement due to the t- α FSI appears in the middle energy region, as seen in fig. 4. The corresponding d-a FSI enhancement in the case of the deuteron energy spectrum for ⁶Li should

exist in an unobserved low-energy region. Thus, in the case of the reaction consisting of three particles in the final state, the measured energy spectrum must be analyzed for each FSI channel in a three-body model and also corrected for any unobserved low-energy part, before the energy integration of the double differential cross section obtained is carried out, in order to compare the experimental result with DWBA calculations.

The measured and analyzed data on the differential cross section for the ${}^{6}\text{Li}(n,d){}^{5}\text{He}(P_{3/2})$ reaction in the center-of-mass (c.m.) system are summarized in fig. 5 and also table 1. The cross section data¹⁾ at each angle has been obtained from the measured energy spectrum by making a correction for the unobserved lower-energy region on the basis of the Watson-Migdal form. The curve drawn in fig. 5 is the result of the EFR-DWBA calculation¹⁾. The sharp rise in the backward angular distribution predicted by the EFR-DWBA calculation is in favor of our data³⁾.

The measured data on the c.m. differential cross section for the ⁶Li $(n,t)^{4}$ He reaction are summarized in fig. 6 and also table 1. The curves in fig. 6 are the result of the EFR-DWBA calculations in both cases of the incoherent sum of the d-pickup amplitudes only (the solid line)¹⁾ and the coherent sum between the d-pickup and ³He-pickup amplitudes (the dashed line)²⁾.

The optical potential parameters used in the EFR-DWBA calculations are summarized⁵⁾ in table 2 for the n-⁶Li and the n-⁷Li reactions in our works. We used the optical potentials of Hyakutake et al.¹⁴⁾ for the entrance channels of n-⁶Li and n-⁷Li. All the EFR-DWBA calculations in our works have been performed by using the code DWUCK¹⁵⁾.

The data on the c.m. differential cross sections for the reactions

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⁷Li(n,d)⁶He(g.s., 0⁺) and ⁷Li(n,d)⁶He^{*}(1.80 MeV, 2⁺) are shown in fig. 7 and also table 3. The measured cross section for ⁷Li(n,d)⁶He^{*}(1st, 2⁺) has been corrected for a contribution from ⁷Li(n,d)ann by means of the analysis of the measured deuteron energy spectrum⁶). Our previous data⁵) on the differential cross section for ⁷Li(n,d)⁶He^{*}(1st), which are larger in the magnitude by a factor of 3 than the present data⁶) as well as than the EFR-DWBA predictions⁵, should be revised by the correct reanalysis of background subtraction and/or of the ⁶He (+ ann) breakup contribution.

The curves drawn in fig. 7 are the result of EFR-DWBA calculations⁵⁾ using the same potential parameters as those of Bingham et al.¹⁶⁾, who obtained the d-⁶Li potential, for the d-⁶He exit channels.

The measured data on the c.m. differential cross section for the ⁷Li $(n,t)^{5}$ He reaction are shown in fig. 8 and also table 4. The data^{4,6}) for ⁷Li $(n,t)^{5}$ He $(P_{3/2})$ have been derived by the same way as that used in the ca⁻e¹) of ⁶Li $(n,d)^{5}$ He $(P_{3/2})$ without involving a plane-wave final-state component¹³) in the n- α scattering state and some FSI channels other than the P_{3/2} n- α channel. The curves in fig. 8 are the result of the EFR-DWBA calculations⁵.

Spectroscopic factors were extracted from the experimental data in comparison with the EFR-DWBA results in a similar way to that described in ref. 1. The result of the spectroscopic factors obtained are summarized in table 5 in comparison with shell model predictions^{17,18,19}) and calculated coefficients of fractional parentage (CFP)^{20,21}) as well as with three-body cluster model predictions²². The present result seems to be almost consistent with the theoretical predictions except the shell model predictions of Cohen and Kurath¹⁷) giving somewhat small factors. A highly accurate analysis would be required to extract more

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precise information about spectroscopic factors for ^{7}Li , as performed for the ^{6}Li case^{1,23)} taking into account state configuration mixing.

4. Conclusions

The differential cross sections for the 14.1 MeV neutron induced reactions of charged-paprticle (d and t) emission from 6,7 Li have been measured and summarized in this paper. Our experimental data are in fair agreement with the Zagreb data of 14.4 MeV.

Our experimental data have given clear evidence of the backward increase of the ${}^{6}\text{Li}(n,d){}^{5}\text{He}$ cross section, predicting by the EFR-DWBA calculation¹⁾ based on the proton pickup mechanism. Generally, the EFR-DWBA calculations based on the pickup mechanism of one- or two-particle transfer reproduce forward differential cross sections for the (n,d) and (n,t) reactions on ${}^{6}\text{Li}$. However, some discrepancies between the experimental data and the DWBA calculations appear over the whole angular region, especially at very backward angles. For example, a coherent sum of the deuteron and ${}^{3}\text{He}$ pickup amplitudes improves the discrepancy at larger angles than 150° (c.m.) for the ${}^{6}\text{Li}(n,t)$ case.

The experimental data on 7 Li(n,d) 6 He(g.s.) and 7 Li(n,d) 6 He(1st) are well reproduced by the EFR-DWBA calculations based on the proton pickup mechanism.

A contribution of only the n- α FSI to the cross section data on ⁷Li $(n,t)^5$ He is described dominantly by only the deuteron pickup mechanism. The triton knockon mechanism predicts too small cross sections.

The extracted spectroscopic factors in this work have been compared with the theoretical values, predicting to be almost consistent except the values of Cohen and Kurath. However, because of some discrepancies found in detail between theoretical and experimental angular distributions over wide angular regions, further theoretical studies based on DWBA as well as the Faddeev approach should be necessary to extract more precise values of spectroscopic factors especially for 7 Li.

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Telescope	⁶ Li(n,	d) ⁵ He	6 _{Li(n} ,	t) ⁴ He	Ref.
setting angle θ_0 (deg)	C.m. mean angle Θ_d (deg)	dσ(Θ _d)/dΩ ⁺⁺) (mb/sr)	C.m. mean angle O _t (deg)	dσ(Θ _t)/dΩ (mb/sr)	
0	8 ± 5 ^{a)}	48.2 ± 2.4 ^{b)}	8 ± 4 ^{a)}	7.4 ± 0.5^{b}	1)
14	18 ± 8	39.3 ± 2.0	17 ± 8	5.5 ± 0.4	1)
22	27 ± 8	30.0 ± 1.5	28 ± 9	2.7 ± 0.2	1)
30	35 ± 7	24.6 ± 1.3	36 ± 7	2.1 ± 0.2	1)
40	50 ± 6	10.2 ± 0.5	50 ± 7	2.0 ± 0.2	1)
50	62 ± 6	7.3 ± 0.4	64 ± 6	1.5 ± 0.2	1)
60	74 ± 5	3.0 ± 0.3	71 ± 5	1.3 ± 0.2	1)
93	110 ± 5	1.4 ± 0.5	110 ± 5	1.8 ± 0.2	2)
100	116 ± 4	2.5 ± 0.6	117 ± 4	1.7 ± 0.2	2)
115	130 ± 4	5.0 ± 0.8	131 ± 4	1.4 ± 0.1	3)
130	144 ± 3	6.4 ± 2.0	145 ± 3	1.7 ± 0.3	2,3)
17			157 ± 9	1.3 ± 0.10 ^{c)}	1)
11			165 ± 9	2.0 ± 0.14^{c}	1)
3			172 ± 6	2.3 ± 0.14^{c}	1,2)

Table 1 Measured c.m. differential cross sections for the reactions 6 Li(n,d)⁵He and 6 Li(n,t)⁴He at 14.1 MeV.

+) The angle corresponding to ⁵He(g.s.).

++) The cross section has been corrected for an unobserved low-energy part by means of the n- α FSI theory.

- a) HWHM of the calculated angular frequency distribution.
- b) The error includes the systematic overall error (±4.8%) in addition to the statistical error.
- c) The data from the alpha particle measurement.

Table 2 Optical potential parameters used in the EFR-DWBA calculations. The potential form expression is the same as that given in ref. 1.

		Entrance	Entrance channels		Exit channels			
		n- ⁶ Li	n- ⁷ Li	d- ⁵ He	d- ⁶ He	t- ⁴ He	t- ⁵ He	
Pote	ntial dep	th paramete	ers:			<u> </u>		
v	(MeV)	37.3	37.0	115.0	92.5	138.0	138.0	
W	(MeV)	19.2 ^G	19.0 ^G	0.68 ^S	72.4 ^S	2.0 ^V	2.0 ^V	
V _{so}	(MeV)	31.2	18.8	0.0	17.2	9.2	18.8	
Range	e paramet	ers:						
r ₀	(fm)	1.63	1.60	1.26	2,17	0.93	1.10	
r ₀ '	(fm)	1.43	1.43	1.80	2.35	2.00	2.00	
a	(fm)	0.53	0.50	0.73	0.61	0.70	0.70	
b	(fm)	0.55	0.40	0.31	0.61	0.65	0.65	
rc	(fm)	0.00	0.00	1.40	1.40	1.40	1.40	
Ref.	•	14	14	1	5	1	5	

G: Gauss form. S: Surface Woods-Saxon form. V: Volume Woods-Saxon form.

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Measured c.m. differential cross sections for the reactions $^{7}\text{Li}(n,d)^{6}\text{He}(g.s.)$ and $^{7}\text{Li}(n,d)^{6}\text{He}^{*}(1st)$ at 14.1 MeV.

Telescope	⁷ Li(n,d ₀)	6 _{He(g.s.)}	7 _{Li(n,d1})6	He [*] (1st)	Ref.
setting angle θ _O (deg)	C.m. mean angle O _d ⁺⁾ (deg)	dσ(Θ _d)/dΩ (mb/sr)	C.m. mean angle Θ_d (deg)	dσ(Θ _d)/dΩ (mb/sr)	
0	8 ± 5 ^{a)} 8 ± 5	0.7 ± 0.4^{b} 2.0 ± 0.8	8 ± 5 ^{a)} 9 ± 4	0.8 ± 0.5 ^{b)} 2.5 ± 0.9	6) 5)
5	10 ± 8	2.0 ± 0.8	11 ± 8	2.7 ± 1.0	5)
10	13 ± 9 15 ± 8	1.5 ± 0.6 2.6 ± 1.1	13 ± 9 16 ± 9	1.0 ± 0.6 2.8 ± 1.0	6) 5)
20	25 ± 9 27 ± 7	2.4 ± 0.6 1.4 ± 0.4	27 ± 9 29 ± 7	0.6 ± 0.4 2.5 ± 0.9	6) 5)
30	41 ± 8 40 ± 6	1.0 ± 0.6 1.4 ± 0.6	44 ± 8 43 ± 7	0.4 ± 0.6 1.9 ± 0.9	6) 5)
40	52 ± 8 53 ± 6	0.4 ± 0.3 0.9 ± 0.5	56 ± 8 57 ± 6	0.2 ± 0.3 0.0 ± 0.7	6) 5)
50	65 ± 7 66 ± 5	0.2 ± 0.4 1.1 ± 0.7	71 ± 7 71 ± 5	0.1 ± 0.4	6) 5)
60	78 ± 6	0.6 ± 0.4	83 ± 6		6)
80	100 ± 4	0.2 ± 0.3	107 ± 4		6)

- +) The c.m. angle calculated for the reaction $^{7}\text{Li}(n,d_{0})^{6}\text{He}(g.s.)$ of Q = -7.753 MeV.
- ++) The c.m. angle calculated for the reaction $^{7}Li(n,d_{1})^{6}He^{*}(1st)$ of Q = -9.553 MeV.
- a) HWHM of the calculated angular frequency distribution.
- b) The error is the statistical error only.

Table 4 Measured c.m. differential cross section for the reaction $7_{\text{Li}(n,t)}^{5}$ He at 14.1 MeV.

Telescope setting	Lab. mean angle θ _t	C.m. mean angle $\Theta_t^{+)}$	dσ(Θ _t)/dΩ ^{*)} (E _t ≧ 3.2 MeV)	dσ(Θ _t)/dΩ ^{**)}	Ref.
(deg)	(deg)	(deg)	(mb/sr)	(mb/sr)	
0	5.8	$7.8 \pm 5.^{a}$	20.7 ± 0.6^{b}	11.7 ± 1.1 ^{c)}	6) 5)
0	7.3	$9.4 \pm 5.$	£J•4 ÷ 0•7	14.5 ± 1.2	4)
5 5	7.6 8.5	10.1 ± 5. 11.4 ± 5.	19.4 ± 0.9	13.8 ± 1.1	5) 4)
10 10	9.4 11.1	12.6 ± 5. 14.8 ± 7.	20.9 ± 0.6 19.3 ± 0.9	12.9 ± 1.2	6) 5)
15	15.9	21.4 ± 7.		5.0 ± 0.5	4)
20 20	18.2 20.3	24.4 ± 7. 26.8 ± 7.	16.2 ± 0.6 16.9 ± 0.9	10.4 ± 1.0	6) 5)
25	25.3	33.7 ± 7.		4.8 ± 0.5	4)
30 30	30.4 30.1	40.4 ± 7. 40.0 ± 6.	14.4 ± 0.6 15.8 ± 0.9	5.0 ± 0.7	6) 5)
35	35.0	46.4 ± 7.		5.5 ± 0.5	4)
40 40	39.2 39.9	51.8 ± 7. 52.7 ± 6.	10.6 ± 0.5 15.1 ± 0.8	6.6 ± 0.9	6) 5)
45	44.8	58.9 ± 6.		7.0 ± 0.6	4)
50 50	49.2 49.8	64.3 ± 6. 65.1 ± 5.	14.7 ± 0.3 12.0 ± 0.8	6.7 ± 0.9	6) 5)
55	54.7	71.1 ± 6.		5.4 ± 0.6	4)
60 60	60.1 59.8	77.5 ± 6. 77.2 ± 5.	7.5 ± 0.5 7.1 ± 0.7	2.9 ± 0.6	6) 5)
65	64.7	82.9 ± 5.		3.1 ± 0.5	4)
70	69.8	88.7 ± 5.	3.6 ± 0.7		5)
80 80	79.5 79.8	99.3 ± 5. 99.6 ± 5.	5.3 ± 0.5 2.6 ± 0.7	2.4 ± 0.7	6) 5)
90	89.9	110.1 ± 5.	2.2 ± 0.7		5)

- *) The cross section for tritons of energies larger than 3.2 MeV.
- **) The cross section for the reaction channel $^{7}\mathrm{Li}(n,t)n\alpha$ with the n- α FSI only.
- +) The c.m. angle calculated for the 7 Li(n,t) 5 He(g.s.) of Q = -3.360 MeV.
- a) HWHM of the calculated angular frequency distribution.
- b) The error does not include the systematic error of the correction for an unobserved part of the spectrum by means of the n- α FSI theory.

Table 5 Spectroscopic factors $S_{xy}^{z}(a)$ extracted in this work assuming $S_{np}^{d}(1s) = 1.00$ and $S_{nd}^{t} = 1.50$. $S_{xy}^{z}(a_{j}) = \langle T'T_{z}'\tau\tau_{z} | TT_{z} \rangle^{2}S(1j)$ for a system z (isotopic spin T, the z component T_{z}) made up of clusters x (τ, τ_{z}) and y (T', T_{z}') in relative motion state a_{j} with the transferred orbital angular momentum 1 and total angular momentum j, where S(1j)is the spectroscopic factor of Cohen and Kurath¹⁷⁾.

	This work		Theory			Ref.			
a _j =	^{2s} 1	1d3	1p _{3/2}	¹ p _{1/2}	^{2s} 1	1d3	1p _{3/2}	^{1p} 1/2	
$z = 6_{Li(1^+)}$:									
S ^{6Li} p5He(3/2 ⁻)			0.91	0.93			0.82	0.82	18)
							0.32	0.34	17)
S ^{6Li} d4He(0 ⁺)	0.75	0.07			1.00 ^a				20)
					0.75	0.75			21)
					1.13				22)
$z = {}^{7}Li(3/2^{-}):$									
S ^{7Li} p6He(0 ⁺)			1.0				0.59		17)
		-	- 0.8				0.50		19)
S ^{7Li} p6He(2 ⁺)			1.0				0.22	0.18	17)
		-	0.6				0.10		19)
S ^{7Li} d5He(3/2-)	0.8	0.4			0.45 ^a	0.45 ⁸	L		20)
-	1.0				0.80 ^b	0.80 ^t)		21)
					1.26	1.27			22)

^a The two-particle coefficients of fractional parentage (c.f.p.). ^b $7_{\text{Li}} = t + 4_{\text{He}}$.

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Fig. 1 Experimental layout.

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Fig. 2 Block diagrams of (a) the main electronic system including the α-monitor for T-d neutrons and (b) the timing and counting loss monitoring system.
PA, SA, DLA, AMP and DA: amplifiers; TFA: timing filter amplifier; TSA: timing single channel analyzer; CFD: discriminator; COIN: coincidence circuit; TAC: time-to-amplitude converter; LGS: linear gate stretcher; PHA: pulse-height analyzer; SCL: scaler.



- (b) The background distribution measured by CT1 at 0° without ⁷Li.
- (c) The particle distribution measured by CT2 at 50° with ⁷Li.
- (d) The background distribution measured by CT2 at 50° without ⁷Li.









distributions of deuterons from the reactions 7 Li(n,d₀) 6 He(g.s.) and 7 Li(n,d₁) 6 He^{*}(1st) at 14.1 MeV.



Fig. 8 Measured and calculated C.M. angular distributions of tritons from the ⁷Li(n,t)⁵He reaction at 14.1 MeV.

Appendix

Table	A1	Measured	deuteron	enersy	spectra	from	the	reaction	⁶ Li(n,d) ⁵ He
TUDIC	п	incubut cu	ucuber on	CHCL 67	phecola	1101	0	1 · uc of on	21(ii)a/ iii

T	T	T 00 -0	
e e 6.3	^e d = 13.7 ^e	$\theta_{d} = 20.7^{\circ}$	$\theta_{d} = 27.1^{\circ}$
$E_{d} = \sigma/d\Omega \cdot dE_{d} = E_{d}$	d ⁻ σ/dΩ·dE _d E	d d⁻o/dΩ•dE _d	E _d d ⁻ o/dn.dE _d
(MeV) (mb/sr·MeV) (Me	V) (mb/sr·MeV) (M	eV) (mb/sr·MeV)	(MeV) (mb/sr·MeV)
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	$\begin{array}{cccccccccccccccccccccccccccccccccccc$	$\begin{array}{rrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrr$	$\begin{array}{cccccccccccccccccccccccccccccccccccc$
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	$\begin{array}{cccccccccccccccccccccccccccccccccccc$	$\begin{array}{rrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrr$	$\begin{array}{rrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrr$
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	$\begin{array}{c} 6.66 \pm 1.01 & 9.8 \\ 7.04 \pm 1.05 & 9.6 \\ 6.92 \pm 1.04 & 9.8 \\ 8.35 \pm 1.15 & 9.6 \\ 7.44 \pm 1.09 & 10.6 \\ 6.76 \pm 1.02 & 10.7 \\ 9.69 \pm 1.24 & 10.7 \\ 11.28 \pm 1.34 & 10.3 \\ 15.68 \pm 1.55 & 10.6 \\ \end{array}$	$\begin{array}{cccccccccccccccccccccccccccccccccccc$	$\begin{array}{cccccccccccccccccccccccccccccccccccc$
10.41 18.04 ± 1.73 10.74 10.52 16.31 ± 1.63 10.86 10.64 19.12 ± 1.73 10.98 10.76 20.20 ± 1.72 11.09 10.87 24.96 ± 1.89 11.21 10.99 26.97 ± 1.94 11.33 11.11 29.29 ± 2.01 11.41 11.23 34.83 ± 2.15 11.56 11.34 37.01 ± 2.21 11.66 11.46 33.56 ± 2.11 11.86	$\begin{array}{c} 19.42 \pm 1.66 \ 10.7 \\ 18.00 \pm 1.51 \ 10.8 \\ 22.95 \pm 1.77 \ 10.9 \\ 26.28 \pm 1.86 \ 11.6 \\ 25.84 \pm 1.85 \ 11.3 \\ 23.79 \pm 1.77 \ 11.4 \\ 22.66 \pm 1.73 \ 11.5 \\ 14.40 \pm 1.39 \ 11.6 \\ 8.59 \pm 1.07 \ 11.8 \end{array}$	$\begin{array}{cccccccccccccccccccccccccccccccccccc$	$\begin{array}{cccccccccccccccccccccccccccccccccccc$
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	$\begin{array}{cccccccccccccccccccccccccccccccccccc$	$\begin{array}{cccccccccccccccccccccccccccccccccccc$	11.92 0.00 ± 0.00 12.04 0.00 ± 0.00

at 14.1 MeV. (The data from fig. 3 in ref. 1.)

The error is given in FWHM.

The corrections have been carried out for background, energy losses of deuterons in the target and the counter gas, and degraded neutron effects.

Table A2 Measured triton energy spectra from the reaction $^{7}Li(n,t)^{5}He$ at 14.1 MeV. (The data from ref. 6.)

θ ι	= <u>5.</u> 8*	9.4	18. 2°	30. 4°	39 . 2*
Εı	d²σ⁄dΩdEı	d²σ⁄dΩdEt	d² σ ∕d Ω dEι	d²σ∕dΩdEı	d²σ∕dΩdEι
(MeV)	(mb/srMeV)	(nnb/srMeV)	(mob∕srMeV)	(mb/srMeV)	(mb/srMeV)
3. 2	6.4±0.9	6.1±0.9	6.5±0.9	5.7±0.9	3.3±0.6
3.4	5.4±0.8	4.8±0.8	5.2±0.8	6.1±0.9	3.5 ± 0.7
3.6	5. 2 ± 0. 8	4.4±0.8	3.7±0.7	6.7±0.9	2.3 ± 0.6
3.8	5.3±0.8	4.8±0.7	2.3 ± 0.6	6.0 ± 0.8	2.0 ± 0.6
4.0	5.4±0.8	5.7±0.8	2.1±0.6	5.5±0.8	1.6±0.4
4. 2	5.4±0.8	5.8±0.8	2.8±0.7	4.7±0.7	1.0±0.4
4.4	5.1±0.8	5.5±0.8	3.0±0.7	3.4 ± 0.7	1.1±0.5
4.6	4.8±0:8	5.1±0.8	2.2±0.7	2.8 ± 0.7	0.7 ± 0.3
4.8	4.8±0.8	4.5 ± 0.7	1.5±0.7	2.5 ± 0.7	0.7 ± 0.3
5.0	5.2 ± 0.8	5.0 ± 0.7	1.8±0.7	2.0 ± 0.7	1.7±0.6
5. 2	5.2 \pm 0.8	5.0±0.8	1.8±0.7	1.5±0.7	1.5±0.5
5.4	5.0 \pm 0.8	5.4 \pm 0.8	2.0±0.7	2.8 ± 0.8	1.3±0.4
5.6	4.8±0.8	4.7±0.8	2.1±0.8	3.1±0.8	1.2±0.4
5.8	4.8±0.8	5.6±0.8	3.6 ± 0.8	2.8±0.7	1.3±0.4
6.0	5.4±0.8	6.6±0.8	4.4±0.8	4.2 ± 0.8	1.8±0.5
6. 2	5.1±0.7	6.2 ± 0.8	2.6 ± 0.7	4.0±0.8	1.1±0.4
6.4	4.3± 0.7	4.5 ± 0.7	2.4 \pm 0.7	3.3 ± 0.8	1.4±0.4
6.6	4.0±0.7	3.4±0.7	2.3 ± 0.7	3.6±0.7	1.5±0.4
6.8	4.0±0.7	3.0±0.6	2.8 ± 0.7	3.6±0.7	1.1±0.3
7.0	3.7±0.7	2.7±0.6	3.6±0.7	3.2 ± 0.7	1.7±0.5
7. 2	3.4±0.6	2.7±0.6	3.6±0.7	2.5 ± 0.7	1.7±0.6

θ.	a = 5.8°	9.4°	18. 2°	<u>30. 4°</u>	39. 2°
Ει	d²σ/dΩdEι	d² σ/dΩdEι	d²σ∕dΩdEι	d²σ∕dΩdEι	d²σ/dΩdEι
(MeV)	(mb/srMeV)	(mb/srMeV)	(mb∕srMeV)	(mo∕srMeV)	(nno∕srMeV)
7.4	3.3±0.6	2.6 ± 0.6	4.0±0.7	1.6±0.6	1.5±0.6
7.6	3.6±0.7	2.7±0.6	3.2 ± 0.7	1.9±0.6	1.0±0.4
7.8	4.0±0.7	2.6±0.6	4.2±0.7	3.3±0.7	2.6 \pm 0.4
8.0	3.7±0.7	4.4 \pm 0.7	5.9 \pm 0.7	3.7±0.6	4.2±0.6
8. 2	3.8±0.7	4.1±0.7	5.5 \pm 0.7	3.5±0.6	4.8±0.6
8.4	4.2±0.6	4.0 ± 0.6	5.3±0.7	5.0±0.6	6.2 ± 0.7
8.6	4.6±0.6	3.8±0.6	6.1 ± 0.7	5.9±0.7	6.4±0.7
8. 8	5.1 ± 0.7	4.5 ± 0.6	6.6 ± 0.7	5.5±0.6	6.2±0.7
9.0	5.2+0.6	1 9+0 F	6 1 + 0 7	5 6+0 C	6 0 + 0 7
3.0 0.7	5.2-0.0	4.810.0	0.1 ± 0.7	5.8±0.6	
9. 2	5.9±0.7	5.0-0.0	7.9±0.7	5.8±0.8	4.0±0.0
9.4	6.7 ± 0.7	7.3±0.7	9.4 ± 0.8	4.9±0.6	2.7±0.4
9, 6	8.210.8	9.7±0.8	10.1±0.8	3.2 ± 0.5	1.6±0.3
9.8	10.6±0.9	13. 1±0. 9	9.7±0.8	2.0±0.4	1.0 ± 0.3
10.0	12.4±0.9	13.4±1.0	7.6±0.7	1.0±0.3	0.5±0.2
10. 2	11.8±0.9	11.5±0.9	5.7±0.6	0.5±0.1	0.3±0.1
10.4	8.4±0.8	8.5±0.8	3.0 ± 0.4	0.2 ± 0.0	0.1 ± 0.0
10.6	5.1±0.6	4.8±0.5	1.8±0.3	0.1±0.0	
10.8	2.7±0.4	1.8±0.3	1.1±0.2		
11.0	1.2±0.2	0.6±0.1	0.4±0.1		
Σ	44.2±1.0	44.1±1.0	34.7±0.9	27.9±0.9	17.2±0.7 (mb/sr

Table A2 (continued).

The error is given in FWHM.

The corrections have been carried out for background, energy losses of tritons in the target and the counter gas, and degraded neutron effects.

$\theta_{t} = 49.2^{\circ}$		60. 2°	7 <u>9.</u> 5°
Ει	d²σ⁄dΩdEt	d²σ∕dΩdEι	d² σ / d Ω dE1
(M∈V)	(mb∕srMeV)	(mb/srMeV)	(mob∕srMeV)
3. 2	5.4 \pm 0.4	3.7±0.8	1.4 ± 0.6
3.4	3.6±0.4	2.6±0.7	1.3 ± 0.6
3.6	2.9 \pm 0.4	2.1 \pm 0.7	1.5 ± 0.5
3. 8	2.8 \pm 0.4	2.0 ± 0.6	1.5±0.5
4.0	3.1 ± 0.3	2.3±0.6	1.5±0.5
4. 2	2.9±0.4	2.1 \pm 0.6	1.4±0.5
4.4	2.9±0.4	1.5 ± 0.6	1.2 ± 0.5
4.6	3.4 ± 0.4	1.4±0.6	0.9 ± 0.3
4.8	3.5±0.4	1.7±0.6	0.4 ± 0.3
5. 0	3.2 ± 0.4	1.7±0.6	0.9 ± 0.5
5. 2	2.9 ± 0.4	1.3±0.6	1.4 ± 0.6
5.4	3.0±0.4	1.2±0.6	1.5 ± 0.7
5.6	3.1±0.4	1.5 ± 0.6	1.8±0.6
5.8	3.3±0.3	1.9±0.5	1.7±0.5
6. 0	3.2 ± 0.3	2.1 \pm 0.5	1.3±0.6
6. 2	2.9±0.3	2.1±0.6	1.2 ± 0.5
6.4	2.8 \pm 0.4	2.1 \pm 0.6	0.9 ± 0.3
6.6	2.6±0.3	2.2 ± 0.6	0.6 ± 0.2
6.8	2.9±0.3	2.5 ± 0.6	
7.0	3.5 ± 0.3	2.1±0.6	
7.2	4.2±0.4	1.6 ± 0.5	
7.4	5.0±0.3	1.5±0.5	

Table A2 (continued).

Table	A2	(continued).

E

$\theta \iota = 49.2^{\circ}$		60. <u>2</u> °	79. 5°	
Еt	d²σ∕dΩdEι	d² σ /d Ω dEι	d² σ∕d Ω dE	i i
(MeV)	(mb/srMeV)	(mb/srMeV)	(mb/srMeV)
7.6	5.2 \pm 0.3	1.2±0.3		
7.8	5.9±0.3	0.6±0.3		
8.0	6.1±0.4	0.2±0.1		
8.2	5.4 \pm 0.4	0.1±0.0		
8.4	4.4±0.3			
8.6	3.2 ± 0.3			
8.8	2.1 \pm 0.3			
9. 0	1.6 ± 0.2			
9. 2	1.1 ± 0.2			
9.4	0.4 ± 0.2			
9.6	0.2 ± 0.1			
9. 8	0.1 ± 0.1			
10.0	0.1±0.1			
Σ	23. 1 ± 0. 4	10.1±0.6	5.7±0.5	(nnob∕sr)

The error is given in FWHM.

The corrections have been carried out for background, energy losses of tritons in the target and the counter gas, and degraded neutron effects.