ON THE MECHANISM OF THE $^{27}Al(\alpha, t)$ REACTION

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The $^{27}Al(\alpha, t)^{28}Si$ reaction has been studied at three bombarding energies: 26.2, 26.45 and 26.7 MeV. The energy-averaged distributions for two states populated in ^{28}Si have been compared with the finite-range DWBA calculations and Hauser-Feshbach theory. Spectroscopic amplitudes were calculated using the available shell-model wave functions.

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1. Introduction

Studies of the (α, t) reaction can give some useful structure information concerning the wave functions of the nuclear states involved providing that the mechanism of the investigated reaction is well understood. This means that the following conditions should be fulfilled:

1. full finite-range distorted wave program should be used to analyse the direct part of the reaction cross section,

2. contributions from the compound nucleus should be properly taken into account,

3. experimental data should be averaged over a suitable energy interval in order to avoid interference terms between direct and compound amplitudes.

In our previous paper [1] we have shown that the energy-averaged angular distributions of deuterons from the $^{27}Al(\alpha, d)^{29}Si$ reaction at E_α around 26 MeV can be nicely

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described as an incoherent sum of the direct and compound processes. The aim of the present investigation is to test the applicability of this approach to the case of the $^{27}Al(\alpha, t)^{28}Si$ reaction. The advantage of this reaction is that the necessary spectroscopic amplitudes can be calculated from the available wave functions of the initial and final nuclear states [2]. Further advantage is that the other input parameters for the DWBA and compound model calculations are rather well known from other investigations [3–5].

2. *Experimental method*

The measurements were performed with the alpha-particle beam accelerated by the U-120 cyclotron of Institute of Nuclear Physics in Cracow. The experimental set-up has been described previously [6, 7]. Therefore only details most important and specific to this experiment will be repeated. The targets were self-supporting foils of ^{27}Al and their thicknesses have been determined by weighing and surface measurements. In order to reduce

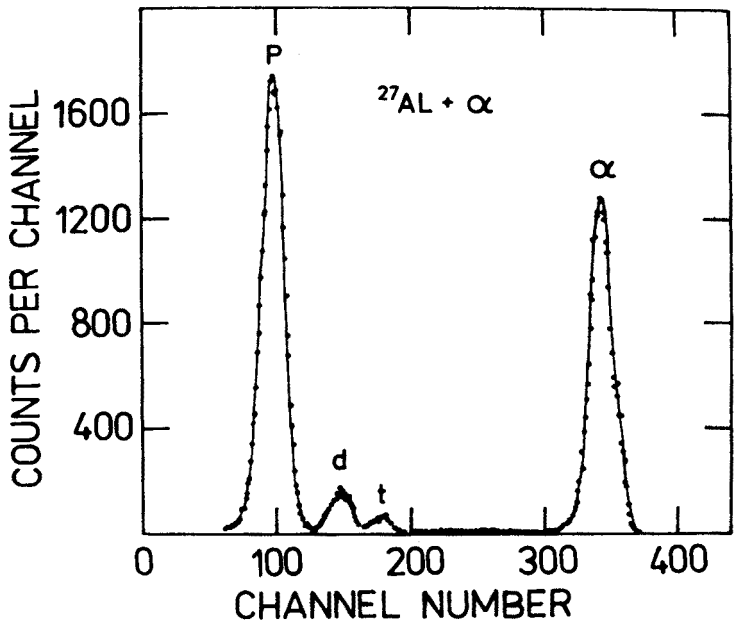

Fig. 1. Typical mass-spectrum for the $^{27}Al(\alpha, t)^{28}Si$ reaction

the error due to the non-uniformity of the target, measurements were made using three targets of different tnicknesses (0.605, 0.783 and 0.900 mg/cm^2). The outgoing particles were detected with the telescope counter consisting of the 100 μm surface barrier silicon detector ΔE and 4 mm lithium-drifted silicon detector E. A typical mass-spectrum is shown in Fig. 1.

The angular distributions of emitted tritons were measured in 10° steps for laboratory angles between 20° and 170° at beam energies of 26.2, 26.45 and 26.7 MeV. Fig. 2 presents

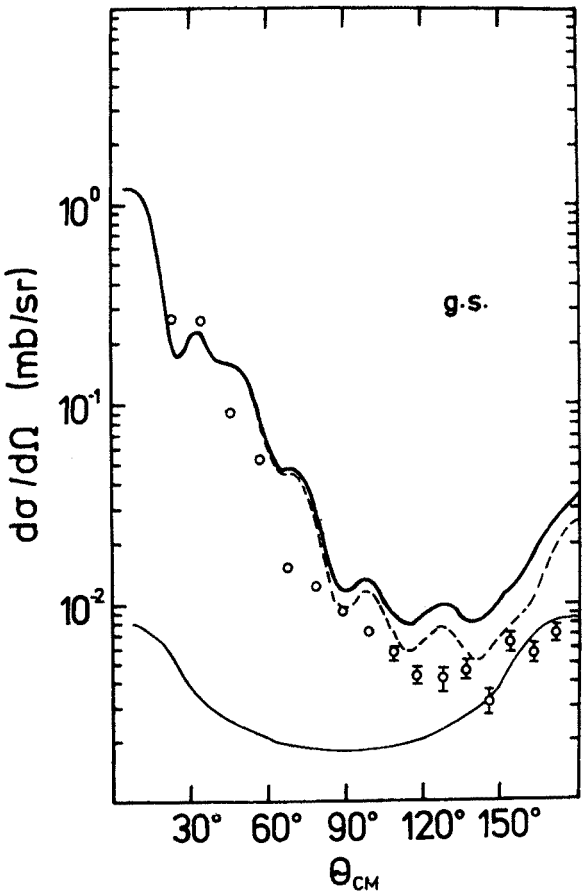

Fig. 3

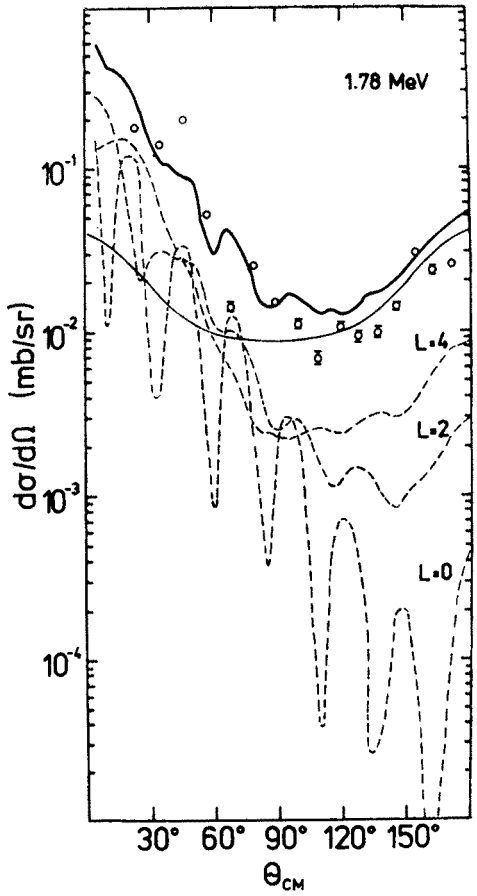

Fig. 4

Fig. 3. Comparison of the angular distribution for the $^{27}Al(\alpha, t)\,^{28}Si$ reaction with the DWBA and Hauser-Feshbach calculations. The dashed line represents the finite-range DWBA calculations, the thin continuous line represents the Hauser-Feshbach calculations and the solid line represents the sum of direct and compound nucleus reaction cross sections. Only the error bars exceeding the size of the circles are marked in the figure

Fig. 4. See Fig. 3

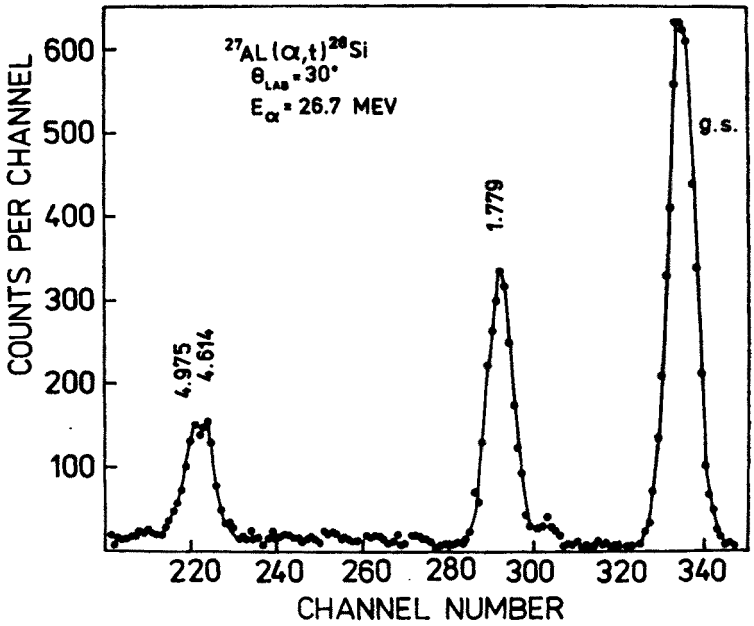

Fig. 2. Triton spectrum for the ^{27}Al(α, t)^{28}Si reaction at 26.7 MeV incident energy and at 30° LAB

an example of triton spectrum for the ^{27}Al(α, t)^{28}Si reaction obtained at 26.7 MeV incident energy and at 30° LAB, the energy resolution is 240 keV. The tritons corresponding to the ground and first excited states of ^{28}Si, clearly resolved at all measured angles, have been analysed.

3. Data analysis and spectroscopic factors calculations

The measured angular distributions averaged over three energies are analysed under assumption that the observed differential cross-section can be compared to the incoherent sum of the direct and compound processes [1, 8]:

$$\frac{d\sigma}{d\Omega} = \left(\frac{d\sigma}{d\Omega}\right)_{\mathrm{DI}} + \left(\frac{d\sigma}{d\Omega}\right)_{\mathrm{CN}}.$$

The averaged angular distributions are presented in Figs 3, 4.

The direct reaction cross-sections were calculated with the code LOLA [9] which allows the inclusion of finite-range and recoil effects. The optical model parameters, used in this analysis, are given in Table I, they have been chosen to fit the elastic scattering. The optical model parameters for the entrance channel are taken from Ref. [10]. For the exit channel we have tested several sets of optical model parameters [3, 4, 11] and for further analysis we have chosen the shallowest one, giving the best fit to our experimental data. Table I presents also the necessary geometrical parameters for the bound states, taken from [12, 13].

TABLE I

Optical model and level density parameters

	V (MeV)	a (fm)	r (fm)	W_s (MeV)	a_s (fm)	r_s (fm)	W_v (MeV)	a_v (fm)	r_v (fm)	V_{so} (MeV)	r_c (fm)	a [18] (MeV^{-1})	δ [19] (MeV)	Ref.
$\alpha+^{27}Al$	49.1	0.572	1.701	—	—	—	7.34	0.572	1.701	—	1.3	3.645	1.80	[10]
$n+^{30}P$	48.5	0.70	1.18	12.1	0.45	1.28	—	—	—	11.0	—	4.050	0	[20]
$p+^{30}Si$	49.8	0.65	1.16	6.5	0.64	1.16	—	—	—	—	1.16	4.050	3.76	[21]
$d+^{29}Si$	123.0	0.945	0.89	—	—	—	27.31	0.539	1.385	—	1.3	3.915	2.09	[22]
$t+^{28}Si$	56.3	0.72	1.4	—	—	—	50.1	0.72	1.4	—	1.4	3.780	3.89	[3]
bound state t+p [12]		0.4	1.39											
bound state Al+p [13]		0.65	1.25											

For the one-nucleon transfer reaction A(a, b)B with B = A+x and a = b+x, the differential cross-section can be written as:

$$\sigma(\theta) = \frac{2J_B+1}{2J_A+1} C^2_{AB} c^2_{ab} S_{ab} \sum_{LM} (2L+1) S^L_{AB} W^2(l_1 j_1 l_2 j_2; s_x L) \sigma^L_{LOLA}(\theta),$$

where J_A and J_B are the total angular momenta of A and B nucleus, respectively; C_{AB} and c_{ab} are the isospin Clebsch-Gordan coefficients; $(l_1 j_1)$ and $(l_2 j_2)$ refer to the shell model orbitals of the transferred nucleon in the projectile and final nucleus, respectively; W is a Racah coefficient; s_x is the spin of the particle x and L is the angular momentum transfer.

The S^L_{AB} is the spectroscopic factor for the transferred nucleon and $c^2_{ab} S_{ab}$ value depends only on reaction type and for (α, t) reaction is equal to 2. The spectroscopic factor S^L_{AB} can be expressed as:

$$S^L_{AB} = |\Sigma^{[nlj]J} S^{1/2}_{AB}([nlj]; JT)|^2$$

and further:

$$S^{1/2}_{AB}([nlj]; JT) = \Sigma^{pq} A_p B_q S^{1/2}_{pq}([nlj]; JT),$$

where A_p and B_q are amplitudes of the shell model calculation wave functions. The L, J, T are quantum numbers of the transferred nucleon and $[nlj]$ defines the single particle state of the transferred nucleon. The spectroscopic amplitudes $S^{1/2}_{pq}$ have been calculated according to McFarlane and French [14] and Towner and Hardy [15] using the wave functions given by Wildenthal and McGrory [2]. The calculated spectroscopic amplitudes $S^{1/2}_{pq}$ are given in Table II. The compound nucleus formation cross-section was calculated by means

TABLE II

Spectroscopic amplitudes for ^{27}Al–^{28}Si

	E_x (MeV)	L	S	J	$d_{5/2}$	$d_{1/2}$	$C^2_{AB} S^L_{AB}$
0+	0.00	2	1/2	5/2	−2.0403	—	2.081
2+	1.78	0	1/2	1/2	−0.0483	−0.4162	0.1079
		2	1/2	3/2	−0.1577	0.0239	0.0519
		2	1/2	5/2	−0.1886	—	
		4	1/2	7/2	−0.2150	—	0.0809
		4	1/2	9/2	−0.1814	—	

of the Hauser-Feshbach formalism using the computer code STATIS [16]. Details of the calculations are given in Ref. [7]. The optical model parameters for five reaction channels: (α, α), (α, p), (α, n), (α, d) and (α, t) along with level density parameters and pairing energies, together with references, are listed in Table I.

The contributions of the compound nucleus mechanism are 4% and 32% for the transitions to the ground and first excited states of the ^{28}Si nucleus, respectively.

In Figs. 3 and 4 the angular distributions of the direct and compound nucleus processes for ground and first excited states of ^{28}Si nucleus are shown.

4. Discussion

This work has been carried out to investigate the importance of direct and compound nucleus contributions to the $^{27}Al(\alpha, t)^{28}Si$ reaction. The present study continues similar preceding studies in ^{27}Al nucleus [1, 7, 17]. Unlike the elastic scattering of the α-particles [8, 10], for which the initial and final channels are the same, the (α, p), (α, d) and (α, t) reactions can be reproduced quite well by means of the finite-range DWBA and the Hauser--Feshbach calculations.

In Table III the values of the spectroscopic factors used in this work are compared to those obtained from other experiments. Our spectroscopic factors were obtained from

TABLE III

Comparison of resulting spectroscopic factors with other experimental data

E_x (MeV)	L	$C^2_{AB}S$				
		Lebedev et al. [4] (α, t)	Nemets et al. [5] (α, t)	Bohne et al. [13] (d, n)	Barnard et al. [23] (^{3}He, d)	This work (α, t)
0.00	2	3.48	2.64	1.50	2.64	2.081
1.78	0	0.12	0.276	0.186	0.456	0.1079
	2	0.24	0.067	0.084	0.084	0.0519
	4	—	0.109	—	—	0.0809

theoretical calculations without any free parameters. It should be mentioned that the values of what is called the experimental spectroscopic factors, were usually obtained by fitting the zero-range DWBA calculated cross section to the experimental angular distribution, neglecting contribution from the compound channel.

We notice a reasonable agreement between the values of the spectroscopic factors obtained from various experiments for the transition to the ground state. In case of the first excited state marked differences are observed which can be attributed to the non--negligible contribution of the compound process.

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