COMPOUND NUCLEUS FORMATION IN THE REACTION $^3H(d, n)^4He$ FOR DEUTERONS OF LOW ENERGY

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The results of measurements of total and differential cross-section and of neutron polarization have been analysed in terms of compound nucleus contribution. The analysis performed seems to point to existence in ^5He of a positive parity state $5/2^+$ at an excitation energy of about 20 MeV.

1. Introduction

Various theoretical approaches have been made to describe the reaction $^3H(d, n)^4He$ for deuteron energies higher than few hundred keV where deviations from the Breit Wigner formula begin to appear.

Direct reaction mechanism and compound nucleus formation with an allowance for some excited states in ^5He have been tried [1], [2].

In the analysis reported here compound nucleus mechanism is assumed to be mainly responsible for the reaction cross-section.

A small contribution from direct reaction mechanism is also taken into account.

2. Data on level structure of ^5He

The $3/2^-$ level describing the reaction cross-section for low deuteron energies is situated at the excitation energy 16.60 MeV and corresponds to deuteron energy of 107 KeV. The structure of higher excited states has been subjected to some theoretical and experimental investigations. Fraser and Spicer [3] have tried to obtain features of the ^5He level spectrum of the basis of a single particle calculations. In this fremework the α-particle is taken as the physical vacuum and even parity states are envisaged either as excitation of the $1p_{3/2}$ neutron to the $2s$–$1d$ shell or as excitation of a $1s_{1/2}$ nucleon to the $1p$ shell; that is the excitations are characterized either as single particle excitations or as 2 particle — 1 hole excitations

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respectively. Calculated level positions are shown in Fig. 1*a* and the results of similar calculations made by Gogsadze and Kopeleishvili [4] are shown in Fig. 1*b*.

Experimental informations on level structure of ^{5}He have been obtained from different reactions. In the measurements of total and differential cross-sections for the ^{3}H(d, n)^{4}He reaction made by Bame and Perry [5] deviations from the Breit Wigner formula have been pointed out with an indication on existence of a level or levels in the excitation energy range between 20 MeV and 22 MeV.

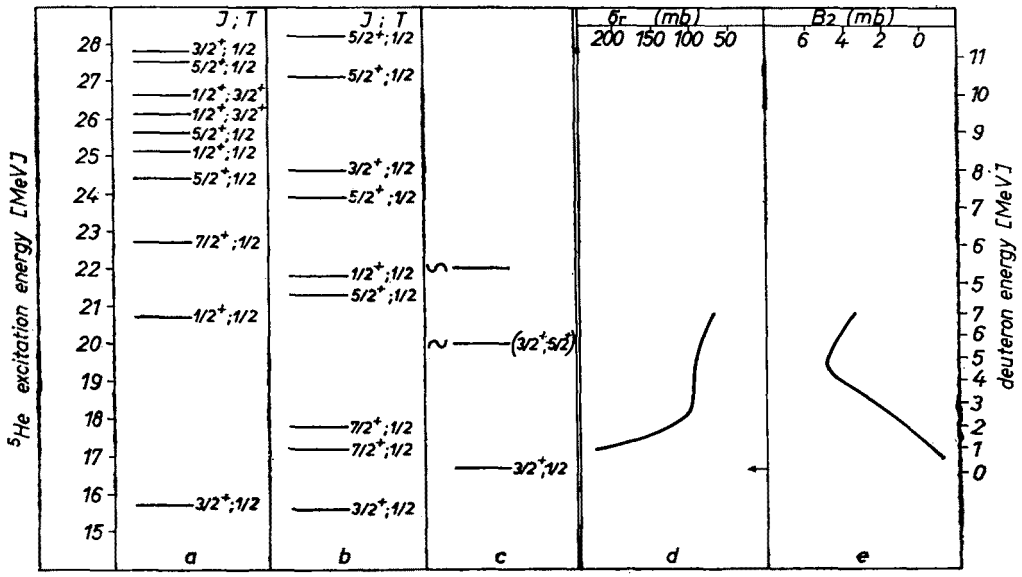

Fig. 1. Energy levels of the compound nucleus ^{5}He suggested in Ref. [3], *a*) and in Ref. [4], *b*). The experimental data on excited states of ^{5}He is shown in *c*). The total reaction cross-section and the B_2 term of the Legendre polynomial expansion of the differential cross-section are shown in Figs *d*) and *e*). The data is from Ref. [5]

Measurements and analysis of differential cross-section for scattering of deuterons on tritium made by Tombrello and others [6] excluded the possibility of existence of negative states (above the $3/2^+$ level at 16.70 MeV) and suggested existence of a level ($3/2^+$ or $5/2^+$) at excitation energy of about 20 MeV. Similar conclusions have been arrived at by Cerny and others [7] in the investigation of the ^{7}Li(p, ^{3}He)^{5}He reaction. The width of that level according to the authors should be about 3 MeV [8].

In the most recent work of Baker and others [9] on the spectrum of α particles from the ^{7}Li(d, α)^{5}He reaction, levels at excitation energies 16.70 20, 22, 25 MeV have been found.

All the experimental data discussed above are displayed in Fig. 1*c*.

3. *Discussion of experimental results of cross-section and polarization measurements*

Total and differential cross-sections for the reaction ^{3}H(d, n)^{4}He have been measured in the energy range 0.5–7 MeV by Bame and Perry [5]. In the excitation curve which evidently deviates from the Breit Wigner formula for 106 keV resonance there are not seen

any other resonances (Fig. 1*d*). Differential cross-section deviates from isotropy expected on the basis of single level analysis giving rise to terms proportional to cos θ and $\cos^2\theta$ (θ — neutron emission angle) in the Legendre polynomial expansion:

$$\frac{d\sigma}{d\Omega} = \sum_n B_n P_n(\cos\theta). \tag{1}$$

As the total cross-section does not show any distinct resonances it seems reasonable that assumed compound nucleus states must be rather broad and weak. This is because of the interference with the main resonance amplitude that their existence is most distincly pronounced giving rise to nonvanishing terms in the Legendre polynomial expansion of the differential cross-section. Levels of negative parity interferring with the main resonance would contribute to the odd terms while those of positive parity to the even ones. Data on polarization of the outgoing neutron also contradicts the single level predictions.Polarization in the low energy region (up to 300 keV deuteron energy) appears to be negligible [10a] and then rises to as much as +16% for the deuteron energy 1.8 MeV at the angle of 90°cm [10b].

In the analysis performed here we use the data of Siemiński *et al.* [11] obtained for the deuteron energy range from a nonpolarizing resonance to a region rapidly increasing polarization *i. e.* from 0.5 up to 1.6 MeV. The angular distribution measured at deuteron energy 1.4 MeV by the authors [11] reflects a sin 2θ dependence. In the analysis reported here existence of only levels of positive parity has been assumed due to the following reasons:

1) only the B_2 term in the Legendre polynomial expansion of differential cross-section shows a resonance structure (Fig. 1*e*),

2) angular distribution of polarization measured at deuteron energy 1.4 MeV [11] points to a sin 2θ dependence characteristic for interference of levels of the same parity (the main resonance level has positive parity),

3) results of the measurement of the cross-section for elastic scattering of deuterons on tritium imply existence of positive parity states above the excitation energy 16.70 MeV with the exclusion of a possibility for existence of negative parity states.

In view of the above arguments direct reaction mechanism would be responsible for the $B1$ term in the differential cross-section and for deviations from the exact sin 2θ dependence of the polarization. A contribution to polarization from direct reaction mechanism may only come from a spin-orbit term in the optical model potential as proton is captured with zero orbital angular momentum. As the spin dependent term in the potential of interaction of low energy deuterons with tritium nucleus is practically unknown no theoretical computation of polarization from direct reaction mechanism has been made in the analysis reported here.

4. Methods of compound nucleus cross-section and polarization calculations

If we denote by I_T, I_C, I_F, $\vec{s}_d$, $\vec{s}_n$ spins of the target, compound and final nucleus and of deuteron and neutron respectively and by $\vec{l}$ and $\vec{l'}$ the corresponding orbital angular momenta of deuteron and neutron we have the relation:

$$\vec{I}_T+\vec{l}+\vec{s}_d = \vec{I}_c = \vec{I}_F+\vec{l'}+\vec{s}_n. \tag{2}$$

Entrance and exit channel spins are defined:

$$\vec{s} = \vec{I}_T + \vec{s}_d \tag{3}$$

$$\vec{s}' = \vec{I}_F + \vec{s}_n. \tag{4}$$

For the reaction $^3H(d, n)^4He$ the entrance channel spin may take a value of 1/2 or 3/2. For the exit channel spin ($I_F = 0$) only one value 1/2 is possible.

The main resonance level $3/2^+$ (at excitation energy 16.70 MeV) is formed with the channel spin 3/2. It then follows that the amplitude of any other transition to some excited state in ^5He, if it is to interfere with the main amplitude — must correspond to the channel spin 3/2.

Differential cross-section has been calculated according to the formula given by Blatt and Biedenharn [12]:

$$\sigma(\theta) = \frac{\lambda\!\!\!^{-2}}{2s+1} \sum_{L=0}^{L_{max}} B_L(\alpha, \alpha')\, P_L(\cos\theta) \tag{5}$$

where

$$B_L(\alpha, \alpha') = \sum_{\substack{J_1, J_2 \\ \pi_1 \pi_2 \\ l_1, l_2 \\ l_1', l_2' \\ s, s'}} \frac{(-1)^{s'-s}}{4} Z(l_1 J_1, l_2 J_2; sL) \cdot Z(l_1' J_1, l_2' J_2; s'L) \times \tag{6}$$

$$\times \operatorname{Re}\left[S^{J_1\Pi_1}(\alpha s l_1; \alpha' s' l_1')^* S^{J_1\Pi_1}(\alpha s l_2; \alpha' s' l_2')\right]$$

α and α' — are entrance and exit channel indices respectively, θ — is neutron emission angle in the centre of mass system, $\lambda\!\!\!^{-}$ — is de Broglie wave length of the incoming deuteron, P_L is the Legendre polynomial of the order L.

Z coefficients are vector addition coefficients discussed by Biedenharn and Blatt [13] with Huby's phase correction [14] applied.

Channel spins and orbital angular momenta are denoted respectively by s and l, spins and partities of compound nucleus levels are denoted by J and π respectively. Primed and unprimed quantities correspond to exit and entrance channels. In calculation of the S-matrix elements one level Breit-Wigner formula with linear dependence of the level shift on deuteron energy has been applied, this approximation is equivalent to zero level shift and corresponding reduced width are "observed" reduced widths defined by Thomas [15]. For the real part of the matrix element we obtain then the following expression [16]:

$$\operatorname{Re}[S^{J_1\Pi_1}(\alpha s l_1; \alpha' s' l_1')^* S^{J_2\Pi_2}(\alpha s l_2; \alpha' s' l_2')]$$

$$= f^{J_1\Pi_1} f^{J_2\Pi_2} \sin\delta^{J_1\Pi_1} \sin\delta^{J_2\Pi_2} \cos(\delta^{J_2\Pi_2} - \delta^{J_1\Pi_1} + \xi^{J_2\Pi_2} - \xi^{J_1\Pi_1}) \ldots \tag{7}$$

where

$$f^{J\Pi} = \pm \frac{2(\Gamma_d^{J\Pi} \cdot \Gamma_n^{J\Pi})^{1/2}}{\Gamma^{J\Pi}} \tag{8}$$

$$\delta^{J\Pi} = \operatorname{arc\,tg} \frac{\Gamma^{J\Pi}}{2(E_R - E_d)} \tag{9}$$

$$\Gamma^{J\Pi} = \Gamma_d^{J\Pi} + \Gamma_n^{J\Pi} \tag{10}$$

$$\xi^l = \sigma_l - \sigma_{l=0} - \zeta_n^l - \zeta_d^l. \tag{11}$$

Quantities $\Gamma_d^{J\Pi}$ and $\Gamma_n^{J\Pi}$ are respectively deuteron and neutron partial width of the level of spin J and parity π. E_R is the resonance energy and E_d the deuteron energy. The partial widths are related to the reduced widths through the equation

$$\Gamma_c^{J\Pi} = 2P_c^{J\Pi}(\gamma^{J\Pi})^2. \tag{12}$$

The penetrability P_c is defined by

$$P_c = \frac{k_c R_c}{F_c^2 + G_c^2} = \frac{\varrho_c}{F_c^2 + G_c^2} \tag{13}$$

where R is the channel radius, F_c and G_c are regular and irregular Coulomb functions evaluated at the channel radius and k is the wave number of relative motion in channel c. The $\pm$ sign appears in Eq. (8) because dispersion theory determines the scattering amplitude only within a relative phase of 180°. These phases have been chosen to provide the proper sign for B_2 term and for polarization and are tabulated with other level parameters in Table I.

TABLE I

Set	level I					level II					
	Spin	Excitation energy MeV	Deuteron reduced width MeV	Neutron reduced width MeV	Relative phase for level I and the main level	Spin	Excitation energy MeV	Deutron reduced width MeV	Neutron reduced width MeV	Relative phase for level II and level I	Relative phase for level II and the main level
A	3/2	15.82	0.816	0.770	(—)	7/2	20.03	3.201	0.112	(—)	(—)
B	1/2	16.67	1.234	0.150	(—)	7/2	20.81	4.280	0.610	(—)	(—)
C	1/2	16.67	1.541	1.270	(—)	5/2	20.05	2.346	0.040	(—)	(—)

Coulomb phase shifts of the wave of orbital angular momentum l is denoted by σ_l and the corresponding hard sphere phase shifts for neutrons und deuterons are denoted by ζ_n^l and ζ_d^l. These phase shifts were calculated according to the formulae:

$$\zeta^l = \operatorname{arc\,tg} \frac{F_l}{G_l} \tag{14}$$

$$\sigma_l - \sigma_{l=0} = \sum_{m=1}^{l} \operatorname{arc\,tg} \frac{\eta}{m} \tag{15}$$

where η denotes the Sommerfeld parameter:

$$\eta = \frac{Z_1 Z_2 e^2}{\hbar \cdot v}$$

Z_1, Z_2 are the atomic numbers of particles, e is the electron charge, v — relative velocity of colliding particles.

Coulomb wave functions were computed using their power series expansion summed over 20 terms. This procedure should yield an accuracy of 10^{-7} [17].

In calculating the cross-section and polarization the following assumptions were made:

1. Radii of entrance and exit channels are 5 fm.
2. In entrance channel the only effective waves are S, P, and D ones.
3. Etrance channel spin is 3/2. (This assumption was made to explain the inference with the main resonance amplitude corresponding to channel spin 3/2.)

A search for the best fit of calculated B_2 values to experimental B_2 terms has been carried out on GIER computer using the least squares procedure called "KWADRACIKI" [18].

The experimental values of the B_1 and B_2 terms used in the analysis performed were taken from the work of Bame and Perey [5] and are shown in Table I. For each level search has been made for level position and entrance and exit channel partial widths. Level spin and corresponding orbital angular momenta in the entrance and exit channels were taken as input parameters for each level in question.

The theoretical B_2 term in the angular distribution has been calculated taking into account contributions from excited levels in the ^{5}He nucleus. One level whose parameters are known [19] is that at excitation 16.70 MeV and corresponding to deuteron energy of 107 keV. Search has been made for six parameters of the two assumed additional levels, *i. e.* for position of each level and for its deuteron and neutron reduced width. Results of the analysis performed may be summarized as follows. At the assumption of only one additional level there it has not been possible for any set of level parameters to obtain a fit of theoretical B_2 values to experimental ones. Assuming existence of two additional levels we have obtained three sets of solutions (Table II).

TABLE II

Experimental values of the B_1 and B_2 term in the Legendre polynomial expansion of the differential cross-section. The data are those of Ref. [5]

Deuteron energy MeV	B_1 mb/sr	B_2 mb/sr
0.50	1.79	−0.88
0.75	1.64	−1.27
1.00	1.86	−0.74
1.25	1.74	−0.45
1.50	1.62	0.03
1.75	1.59	0.57
2.50	1.42	1.36
3.00	1.67	2.13
3.50	1.59	3.15
4.00	1.88	3.98
4.50	1.94	4.74
5.00	2.14	4.83
6.00	2.28	4.18
7.00	1.88	3.34

Parameters obtained from these solutions were then used to calculate the polarization according to the formula [20]:

$$P(\theta) = \frac{\lambda^2}{4\sigma(\theta)} \frac{[2(2i'+1)]^{1/2}}{(2I+1)(2i+1)} \left(\frac{i'+1}{i'}\right)^{1/2} \times$$
$$\times \sum_{\substack{J_1\Pi_1 J_2\Pi_2 l_1 l_2 \\ L l_1' l_2' s_1' s}} j^{l_2-l_1+l_1'-l_2'} \mathrm{Re}\,[j(S^{J_1\Pi_1}(\alpha s l_1; \alpha_1' l_1' s_1')^* S^{J_2\Pi_2}(\alpha s l_2; \alpha' s_2' l_2'))] \times$$
$$\times (-1)^{I'-i'-s+l_1'+J_1-s_1'} [(2l_1+1)(2l_2+1)(2l_1'+1)(2l_2'+1)(2s_1'+1)(2s_2'+1)] \times$$
$$\times (2J_1+1)(2J_2+1)(l_1 l_2 00|l_1' l_2' L0)(l_1' l_2' 00|l_1\, l_2\, L\, 0) \times$$
$$\times W(i' s_1' i' s_2'; I'1) \cdot \mathrm{W}(l_1 J_1 l_2 J_2; sL) \times$$
$$\times X(J_1 l_1' s_1'; J_2 l_2' s_2'; LL1) \cdot P_L^1(\cos\theta) \ldots \tag{16}$$

where $j = \sqrt{-1}$ and the notation in the same as that used in (6) and W and X denote Racah and Wigner $9j$ coefficients respectively. P_L^1 is the associated Legendre polynomial.

5. *Contribution from direct reaction mechanism*

Compound nucleus formation does not give a detail account of experimental data. Deviations from assumed compound nucleus mechanism *i. e.* existence of the B_1 term in the Legendre polynomial expansion (Table I) and the fact that polarization does not strictly obey a sin 2θ dependence can be assigned to a contribution from direct reaction mechanism.

This contribution can be estimated according to Goldfarb and Johnson [21] and treated with the DWBA formalism. It is of course realised that the use of an optical model for the $d+{}^3\mathrm{H}$ reaction is rather a venturesome attempt employed here only in the absence of any better approach. The results obtained can only be interpreted as crude ones.

With two mechanisms participating we can express the reaction matrix in a form:

$$S = S_{\mathrm{res}} + S_D \tag{17}$$

where S_{res} corresponds to a resonance part of the reaction matrix discussed in Section 4 while S_D describes contribution from direct mechanism.

As proton is captured with zero orbital angular momentum the matrix element can be expressed in the form [23]:

$$S_D(\alpha l s, \alpha' l' s') = N_D \delta_{ss'} \cdot \delta_{ll'} \cdot A_L W(I s_1; I' s_2, s\tfrac{1}{2}) \ldots \tag{18}$$

where

$$N_D = -(-1)^{s_1-I-s_2} \frac{4iK_iK_f}{\hbar\sqrt{v_i v_f}} \frac{\Theta}{4\pi} \sqrt{(2s_1+1)(2I+1)} \tag{19}$$

A is a radial integral:

$$A_l = (4\pi)^{3/2} \int_0^\infty r^2\, dr\, \chi^{*(-)}_l(K_f, r) \cdot \varphi_l(r) \cdot \chi^{(+)}_l(K_i, r) \tag{20}$$

In Eqs (18–20) we use the following notation:

α, α' — entrance and exit channel,
l, l' — orbital angular momentum in entrance and exit channel,
s, s' — entrance and exit channel spin,
Θ — the reduced width,
I' — spin of the residual nucleus,
K_i, K_f — wave vector in entrance and exit channel,
v_i, v_f — velocity of relative motion in entrance and exit channel,
s_1, s_2 — spin of deuteron and of neutron,
I — spin of the target nucleus,
$\chi_l^{(+)}\chi_l^{(-)}$ — distorted wave functions for deuteron and neutron, respectively,
$\varphi_l(r)$ — bound state wave function.

The excit channel spin can take only the value 1/2. According to Eq. (18) the entrance channel spin must be also 1/2. In the discussion of compound nucleus mechanism presented in Section 4 we assumed an interference of transitions to postulated levels with the transition to the main 3/2 + level. For that interference to occur the entrance channel spins should be equal. As the direct transition proceeds with entrance channel spin 1/2 it then follows that there should not be any interference between compound and direct amplitudes.

Differential cross-section in the case of direct reaction mechanism can be computed from Eqs (18), (19) and (20).

Sometimes it is more convenient to express the cross-section in a form facilitating a direct comparison with experimental values of the B_n terms in the Legendre polynomial expansion [22], [23]:

$$\left(\frac{d\sigma}{d\Omega}\right)_D = \frac{\lambda^2 N_D^2}{8(2s_1+1)(2I+1)} \sum_L (2l_1+1)(2l_2+1) \times$$

$$\times |\langle l_1 l_2 00 | LO\rangle|^2 \cdot A_{l_1}^* A_{l_1} \cdot P_2(\cos\theta). \tag{21}$$

Computations of the A_l quantities have been made with help of GAP 2 program [24]. The original version of the program has been modified to allow the calculations of Coulomb wave functions for low energy projectiles and low Z targets.

The potential has been taken in the form of Woods-Saxon:

$$U(r) = V_{\text{coul}}(r) + V \cdot \frac{1}{1+\exp\dfrac{r-R_1}{\alpha_1}} + iW \frac{1}{1+\exp\dfrac{r-R_2}{\alpha_2}}. \tag{22}$$

Potential parameters chosen were similar to those of Goldfarb and Huq [1].

They are summarized in Table II.

Bound state wave function (φ_l function in Eq. (20)) has been calculated with Woods-Saxon potential parameters chosen to provide proper binding energy of proton in ^{5}He.

Comparison of the calculated value of the B_1 term with the experimental one yields for the spectroscopic factor the value 0.2. Direct reaction contribution calculated with assumed 0.2 value for spectroscopic factor can be compared with experimental data (Figs 2–4).

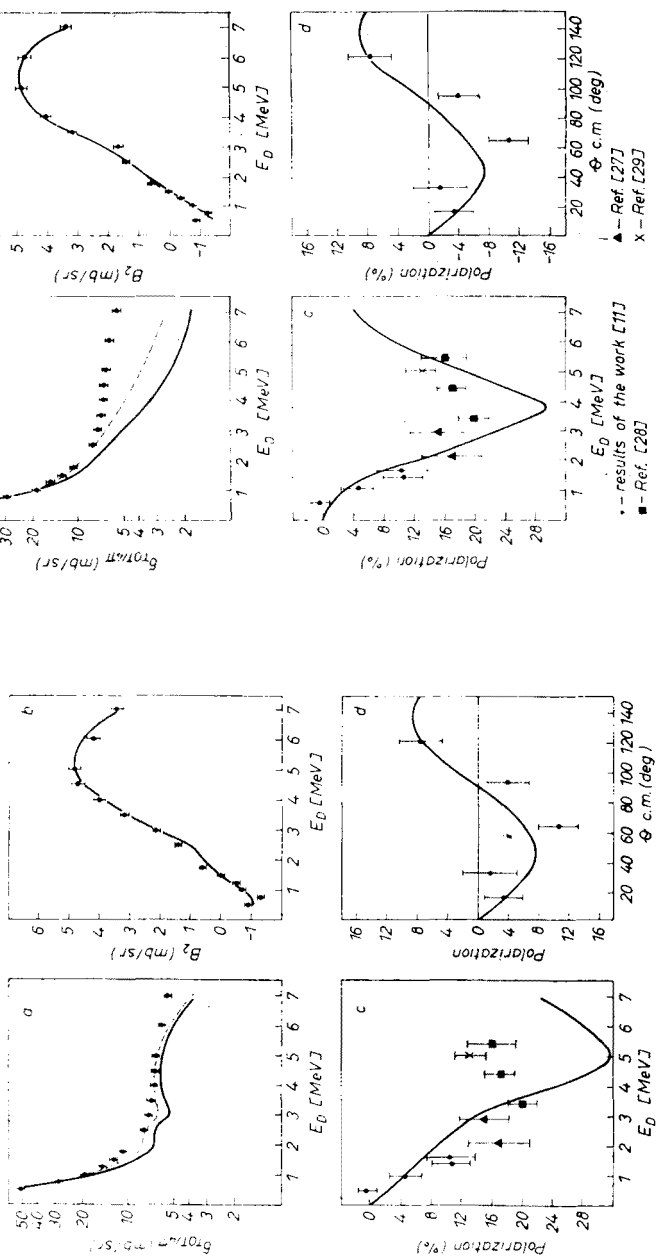

Fig. 3

Fig. 2

Fig. 2. Theoretical fits to experimental data. Level set *A* is assumed. *a*) ——— total reaction cross-section without direct contribution, ------- total reaction cross-section with direct contribution included; *b*) — the B_2 term in the Legendre polynomial expansion of the differential cross-section, experimental data is from Ref. [5]; *c*) — dependence of the polarization of neutrons emitted at 60° (lab.) on deuteron energy; *d*) — angular dependence of neutron polarization for deuteron energy 1.4 MeV

Fig. 3. Theoretical fits to experimental data. Level set *B* is assumed. Notation is the same as in Fig. 2

TABLE III

Potential parameter	V (MeV)	W (MeV)	α_1 (fm)	R_1 (fm)	α_2 (fm)	R_2 (fm)
deuteron	50	5	0.60	$1.50\times A^{1/3}$	0.60	$1.50\times A^{1/3}$
neutron	40	0	0.18	$1.30\times A^{1/3}$	0.18	$1.30\times A^{1/3}$

$$V_{\text{coul}}^{\text{deut}}(r) = \begin{cases} \dfrac{e^2}{r} & \text{for } r \geqslant 1.50 \cdot A^{1/3} = R_c \\ \dfrac{e^2}{R_c}\left(\dfrac{3}{2} - \dfrac{1}{2}\dfrac{r^2}{R_c^2}\right) & \text{for } r < R_c \end{cases}$$

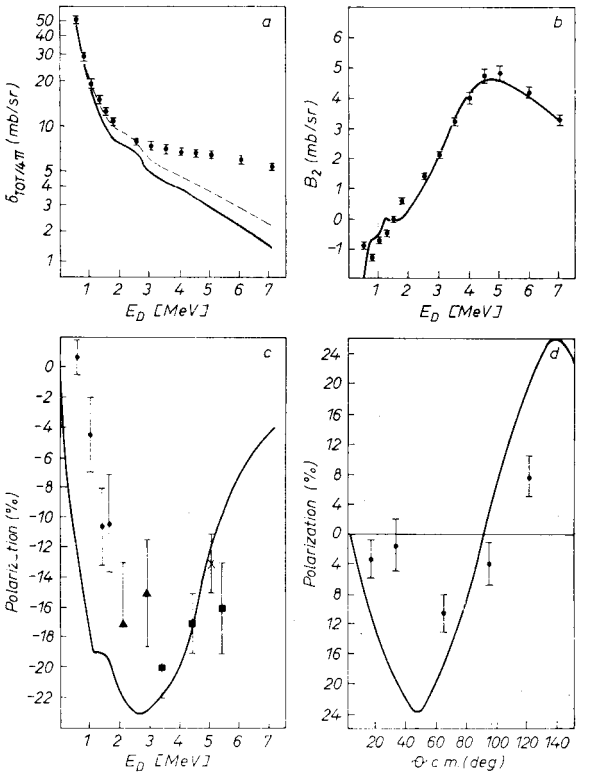

Fig. 4. Theoretical fits to experimental data. Level set C is assumed. Notation is the same as in Fig. 2

6. *Discussion of the results*

Results of the analysis are shown in Figs 2–4 and in Table I. Parameters of assumed levels correspond to the fit of the theoretical value of the B_2 term to an experimental one. Using these parameters total cross-section and polarization have been calculated. Direct

reaction contribution discussed in Section 5 is included in the total cross-section. This contribution can be calculated only approximately as the optical potential parameters for low energy deuterons scattered off tritium are not well known.

As proton is captured with zero orbital angular momentum the polarization in direct reaction mechanism could only be produced by an $\vec{ls}$ term in the optical model potential. The polarization is very sensitive to the deuteron spin-orbit potential [25] which is practically unknown for low energy deuterons scattered on tritium. Consequently, no polarization calculations from direct reaction mechanism have been made. Neglecting the spin-orbit part of the potential should little affect the value of the total cross-section.

Relative contribution of direct reaction mechanism calculated for deuteron energy of 3 MeV amounts to about 15% of the total cross-section. Because direct contribution has been ignored in polarization calculations it seems reasonable to compare the calculated values of polarization with measured ones only in low energy region up to 3 MeV at most.

Inspection of curves in Figs 2–4 shows that the sets *A* and *C* reproduce the experimental values of the B_2 term and the polarization reasonable well. The total cross-section curve calculated with level parameters of the set *C* shows a remarkably better agreement with the experimental data than corresponding curve of set *A*. One may conclude then that best reproducibility of experimental data is obtained with set *C*.

As a word of warning it may be wortwhile to note here that fits of level parameters to the Breit-Wigner formula may be sometimes ambiguous. The possibility of obtaining a number of fits may be due to a large number of orthonormal sets for the expansion of the wave function in the interior region.

Set *C* assumes existence of a $1/2^+$ level round the well known $3/2^+$ level situated at excitation energy 16.70 MeV. Existence of level at this excitation energy has been guessed by Lane and Thomas [26] who considered this state as $1S_{1/2}$ hole coupled the ^{6}Li core (spin of ^{6}Li is 1).

Such a hole state should have a very small neutron width. The reduced width found here (1.27 MeV) may just reflect the mentioned above ambiguities concerning the fits to the Breit-Wigner formula. Existence of a $1/2^+$ level in ^{5}He neat the excitation energy 16.70 MeV is also suggested by Gogsadze and Kopeleishvili [4].

In set *C* there is also assumed existence of a $5/2^+$ level at the excitation energy of about 20 MeV. Existence of level at that excitation energy was suggested in the work of Tombrello and others on the elastic scattering of deuterons on ^{3}H and ^{3}He [6]. The spin assigned to that level was either $3/2^+$ or $5/2^+$. The same spin assignment has been given to that level by the recent work of Cerny and others [7] on the reaction ^{7}Li(p, ^{3}H)^{5}Li and ^{7}Li(p, ^{3}He)^{5}He. The width of the level found in that work is about 3 MeV [8].

According to the analysis performed in this work this level should be assigned a spin 5/2 and a positive parity. The width found is 2.6 MeV.

Lane and Thomas in the mentioned above work [26] suggest existence in that excitation region of a level with spin 5/2 or 7/2. They treat this level as formed by a $1S_{1/2}$ hole coupled to the first excited state of ^{6}Li which has spin 3. This state should have a very small neutron reduced witdh. That is in agreement with the value found in the analysis reported no here (Table I).

REFERENCES

[1] L. J. B. Goldfarb, A. Hug, *Helv. Phys. Acta*, **38**, 541 (1965).
[2] A. Huq, *Helv. Phys. Acta*, **39**, 507 (1965).
[3] R. F. Fraser, B. M. Spicer, *Austral. J. Phys.*, **19**, 849 (1966).
[4] G. Sh. Gogsadze, T. I. Kopeleishvili, *Yadernaya Fizika*, **8**, 875 (1968).
[5] S. J. Bame, J. E. Perey, *Phys. Rev.*, **107**, 1616 (1957).
[6] T. A. Tombrello, R. J. Spiger, A. D. Baker, *Phys. Rev.*, **154**, 935 (1967).
[7] J. Cerny, C. Detroz, R. M. Pehl, *Phys. Rev.*, **152**, 1127 (1968).
[8] R. L. Mc Grath, J. Cerny, S. W. Cosper, *Phys. Rev.*, **165**, 1127 (1968).
[9] M. P. Baker, J. M. Cameron, N. S. Chant, N. F. Manhelson, D. W. Storm, International Conference on Properties of Nuclear States, Montreal 1969.
[10] P. J. Pasma, *Nuclear Phys.*, **6**, 141 (1958); F. Boreli, V. Lazarevic, N. Radisic, *Nuclear Phys.*, **66**, 301 (1965).
[11] M. Siemiński, Z. Wilhelmi, W. Zych, P. Żuprański, J. Rondio, Report IBJ, No 1252/I/PL, 1970.
[12] J. M. Blatt, L. C. Biedenharn, *Rev. Mod. Phys.*, **24**, 258 (1952).
[13] L. C. Biedenharn, J. M. Blatt, *Rev. Mod. Phys.*, **24**, 249 (1952).
[14] R. Huby, *Proc. Phys. Soc.*, **67A**, 1103 (1954).
[15] R. S. Thomas, *Phys. Rev.*, **81**, 1482 (1951).
[16] S. M. Austin, S. E. Darden, A. Okazaki, Z. Wilhelmi, *Nuclear Phys.*, **22**, 459 (1961).
[17] C. E. Fröberg, *Rev. Mod. Phys.*, **27**, 399 (1959).
[18] W. Grochulski, W. Wójcik, Report IBJ No 866/I/PL, 1967.
[19] H. V. Argo, R. F. Taschek, H. M. Agnew, A. Hommendinger, W. T. Leland, *Phys. Rev.*, **87**, 612 (1952).
[20] A. Simon, T. A. Welton, *Phys. Rev.*, **90**, 1036 (1953).
[21] L. J. B. Goldfarb, R. C. Johnson, *Nuclear Phys.*, **18**, 356 (1960).
[22] M. Kozłowski, Private communication.
[23] N. V. Sen, Rapport CEA — R 3305, 1967.
[24] J. Bang, R. Cooper, B. Olsen, Niels Bohr Institute GIER Program Library 1966.
[25] Sven A. Hjorth, J. X. Saladin, G. R. Satchler, *Phys. Rev.*, **138B**, 1425 (1960).
[26] A. Lane, G. Thomas, *Rev. Mod. Phys.*, **32**, 519 (1960).
[27] J. Christiansen, F. W. Büsser, F. Niebergall, G. Söhngen, *Nuclear Phys.*, **67**, 133 (1965).
[28] W. Büsse, J. Christiansen, D. Hilscher, U. Merfeld, J. A. Scheer, W. U. Schröder, *Nuclear Phys.*, **A100**, 490 (1967).
[29] R. B. Perkins, J. E. Simmons, *Phys. Rev.*, **124**, 1153 (1961).