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3.47 Model-free analysis of the first-rank observables in d + d system and unbound states of ^{4}He in giant resonance region

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The polarization phenomena in the d + d system have some unusual features at lab energies 8 - 14 MeV. Although from the analysis of dd elastic cross section the contribution of orbital angular momenta $L > 0$ is well established, the values of the vector analyzing power A_y^{el} are close to zeroes (Fig. 1a) and are much smaller of those for the N + 3N , N + α, d + 3N systems at comparable energy. Around E_{cm} = 5 - 7 MeV the significant decrease of the A_y for d(d,p)t reaction is observed at $\theta_{cm} < 90^o$ with a smooth change of its sign at $\theta_{cm} > 90^o$ (Fig. 1c), whereas the proton polarization P_p passes a broad maximum (Fig. 1b,c). The zero-crossing of the $A_y(E)$ is usually a strong indication for resonant character of interaction. It is also important that the values of A_y and P_p are contradict to the well known receipts given by the theory of direct reactions: if d($\vec{d}$,p)t is the deuteron stripping with $l_n = 0$ then $A_y = \alpha P_p$, $\alpha \geq 1$ is to be expected.

Here an attempt is made to connect the above phenomena with other anomalies which have been discovered for A = 4 in different processes (see [8] for references) : in the RGM-analysis of the dd elastic scattering cross sections an indication was found for a broad 2^+, T = 0 ^{1}D-state at E_x near 30 MeV; besides a broad D-wave anomaly, according to the phase shift analysis of N + 3N system, there exists the 1^-, T = 0 state at $E_x \simeq 29$ MeV; the evidences for a broad 1^- resonance were also found in ^{4}He(d,d´d) and ^{4}He(α, α´x) reactions; the cross sections of photonuclear reactions ^{4}He(γ,N) and ^{4}He(γ,2d) can be described (see also [9,10]) on the basis of broad overlapping resonances 1^- and $2^+(^1D)$ at E_x around 30 - 32 MeV, and so on.

Leaning upon these facts, it is convenient to analyze the first-rank observables as the sums $C(k)P_k^1(\cos\theta)$, the coefficients C(k) being of the following explicit form[11] for the A_y in A($\vec{a}$,b)B reaction

$$C_A(k) \sim \sum_{mn} \delta_{S'_m S'_n} A_{mnk} \begin{pmatrix} L_m & L_n & k \\ 0 & 0 & 0 \end{pmatrix} \begin{pmatrix} L'_m & L'_n & k \\ 0 & 0 & 0 \end{pmatrix} \begin{Bmatrix} s_a & S_m & s_A \\ S_n & s_a & s_A \end{Bmatrix} \begin{Bmatrix} L'_m & L'_n & S_m \\ J_n & J_m & k \end{Bmatrix} \begin{pmatrix} S_m & L_m & J_m \\ S_n & L_n & J_n \\ 1 & k & k \end{pmatrix} \mathrm{Im}(M_m M_n^*) \qquad (1)$$

here $M_m = (S'_m L'_m J_m | M | S_m L_m J)$ is the matrix element (ME) of the amplitude M for a transition from a state with channel spin S_m and orbital angular momentum L_m to a state with S'_m, L'_m . For the polarization P in A(a,$\vec{b}$)B reaction s_a, s_A are changed by s_b, s_B and all the primed and unprimed symbols are interchanged.

Considering the A_y^{el} on the basis of eq.(1), it is easy to see that the ME $2^+$of the types $^1D_2 \rightarrow {}^1D_2$ (022|M|022), $^1D_2 \rightarrow {}^5D_2$ (222|M|022) and $^1D_2 \rightarrow {}^5S_2$ (202|M|022) are not allowed in the $C_A^{el}(k)$. The 1^- ME $^3P_1 \rightarrow {}^3P_1$ (111|M|111) may contribute only through interference with the ME (112|M|112), (132|M|132), (133|M|133) and (134|M|134). But neither the known theoretical predictions nor the experimental results give 2^-, 3^-, 4^-, T = 0 states in this energy range[8]. Thus the experimental data $A_y^{el} \rightarrow 0$ at E_{cm} = 4 - 7 MeV can be explained in the case of isolated or overlapping 1^- and 2^+ states.

The analysis of d(d,p)t reaction is complicated because of very large number of allowed ME-combinations[6]. In addition, the process may partially proceed with $\Delta T = 1$ due to isospin mixing at $E_x \simeq 30$ MeV, which concerns especially[10] the 1^- level, and the states of giant dipole resonance of ^{4}He can be involved. The first-rank observables turn to zeroes for a single ME. For the d(d,p)t reaction there are two ME corresponding to the 1^- resonance (α_{11} = (111|M|111) and β_{11} = (011|M|111)) and two ME corresponding to the ^{1}D-resonance 2^+ (α_2 = (022|M|022) and β_2 = (122|M|022)). But according to eq.(1), the A_y should be equal to zero either for both ^{1}D-ME α_2 and β_2 or for both 1^- ME α_{11} and β_{11} contribution. Moreover, the A_y is also equal to zero in the cases of interference $\alpha_{11}\alpha_2$ and $\beta_{11}\beta_2$. On the contrary, for polarization P_p the 'coherent' combinations $\alpha_{11}\beta_{11}$ and $\alpha_2\beta_2$ are allowed in the coefficient $C_P(2)$ (which is dominating, Fig.1b), i.e. the P_p can be large for either isolated or overlapping 1^- and 2^+ resonances. On the other hand the observed small values of $A_y \neq 0$ at $E \sim 12$ MeV, with the prevalence of $C_A(1)$[6], are quite difficult for explanation. The possible reason is the interference of $\alpha_0\beta_{11}$ (α_0 = (000|M|000)), $\alpha_2\beta_{11}$ and $\beta_2\alpha_{11}$, which is influenced by the large number of other also randomly phased bilinear combinations.

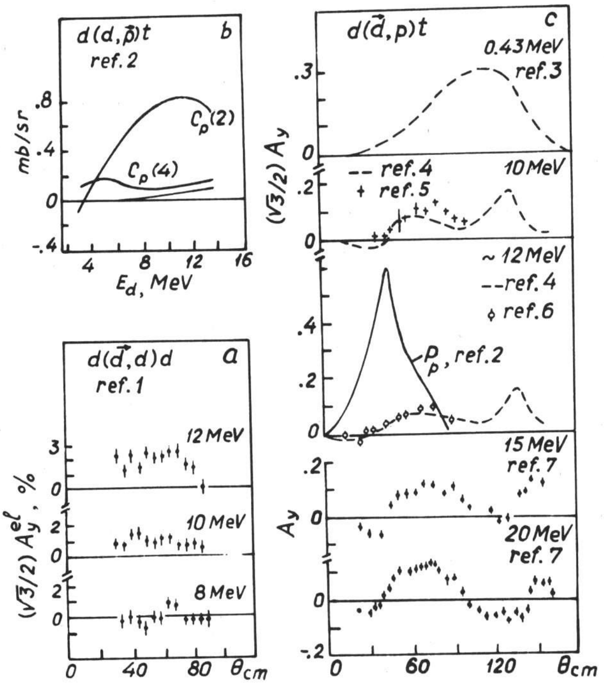

Fig.1. The first-rank data for d + d system (experiment)

In addition some features of even-rank observables[4], which are compatible with the resonances under consideration, should be briefly mentioned: the main contribution of $d_{00}(4)$ to the d(d,p)t cross section may be due to the resonating ME α_2; the relation[12] $d_{20}(1) = -\sqrt{2/3}\, d_{21}(1)$ is almost ideally satisfied that may correspond to the interference of resonant β_{11} with α_0; the $d_{20}(4)$ gives the main contribution to the T_{20} and has a resonant-like behaviour, which may be due to interference of α_2 and β_2 with other (nonresonant?) 2^+ ME ((022 M 222), (122 M 222)) as well as due to interference of the α_{11} with nonresonant J^-, $J \geqslant 3$. The analysis of the even-rank observables is also highly complicated because of many possible ME-combinations, and one has to be cautious to avoid discoveries of false resonances.

In that way the polarization phenomena in d + d system do not contradict to the existing ideas[8] about broad 1^- and 2^+ resonances of ^{4}He at $E_x \sim 30$ MeV and, moreover, can be understood on that basis at least qualitatively.

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