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ALPHA INDUCED DEUTERON BREAKUP AT LOW ENERGIES

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To investigate the continuum of the $A = 6$ system, we performed a series of experiments concerning the reactions:

$$^2H(\alpha, \alpha)^2H , \tag{1}$$

$$^2H(\alpha, p\alpha)n . \tag{2}$$

These experiments have been carried out in a kinematically complete way, i.e. detecting two of the outgoing particles. The details of the experimental set-up have been described elsewhere[1-3].

To investigate reactions (1) and (2) we used the $^4He^{++}$ beam of the 7 MV Van de Graaf of the Laboratori Nazionali di Legnaro. The alpha incident energy ranged from 6 to 14 MeV. Solid deuterated targets[4] have been used to achieve high counting rates, good angular and energy resolution.

Further measurements have been done using the polarized deuteron beam of the ETH-Zürich Tandem in collaboration with the group of Prof. Grüebler. Gaseous ^4He targets have been used with a very thin window of ~ 50 $\mu g/cm^2$ of polypropylene in order to detect α-particles having energies smaller than 1 MeV. The aim of the latter measurements is to determine
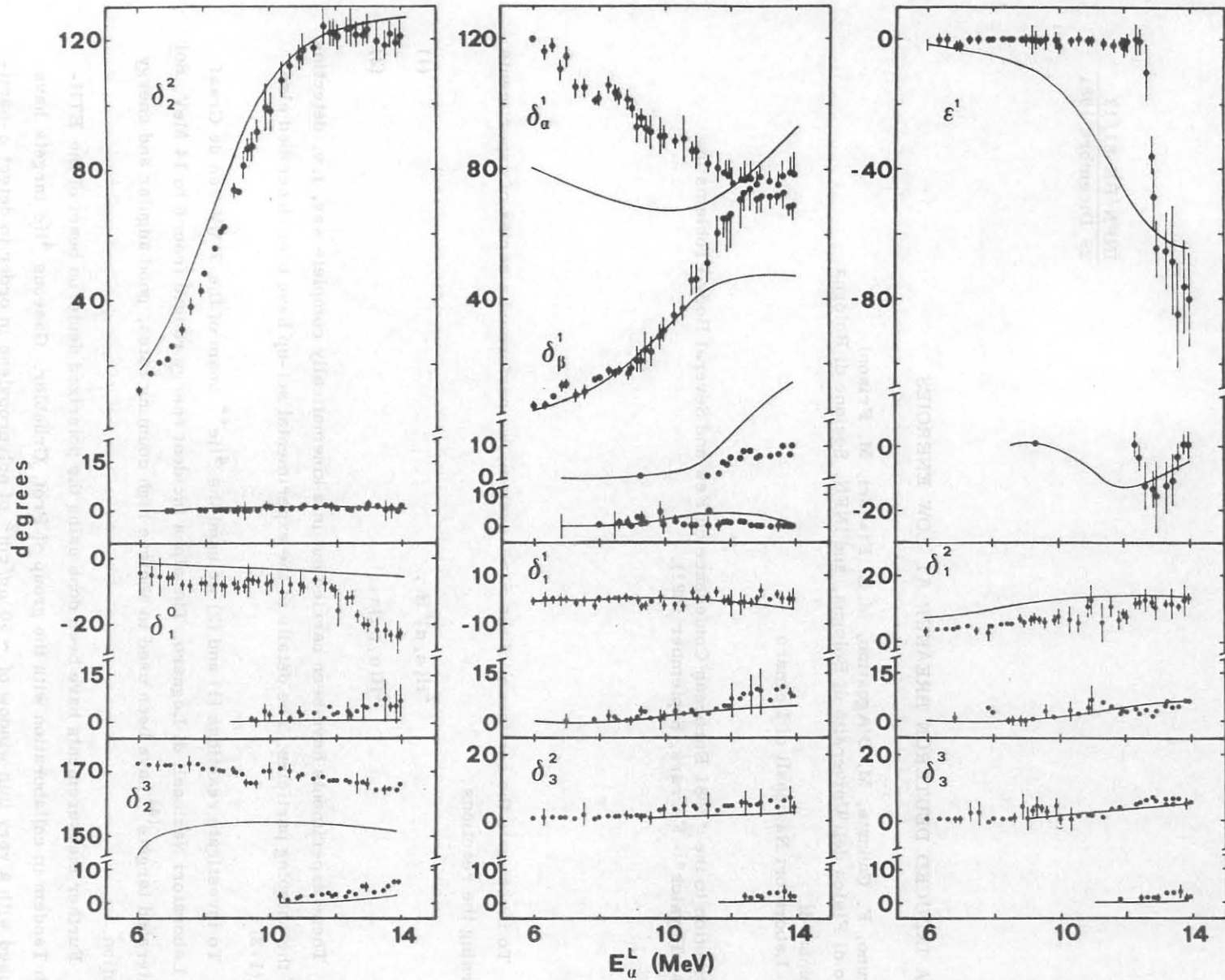
FIG. 1 - Real and imaginary part of the phase-shifts and mixing parameter obtained in ref. (1) as a function of the α-incident energy. The continuous lines are calculations[1,5] based on Faddeev equations.

vector and tensor analysing power of the reaction

$$^4\text{He}(\vec{d}, p\,\alpha)n .$$ (3)

The experiment is in a very early stage and we have only obtained very preliminary results for $\langle iT_{11} \rangle$ in the kinematical configuration $E_{\vec{d}} = 10$ MeV ; $\theta_\alpha = \theta_p = 46^\circ$.

In analysing reactions (1), (2) and (3), the theoretical assumption usually made to interpret the experimental results are :

a) the $A = 6$ system is approximated as a three cluster system $\alpha + p + n$, i.e. the α-particle is considered as an elementary particle, whereas the deuteron is treated as a composite $(p + n)$ one ;

b) only two-body forces αn, αp and np are assumed.

These two hypothesis have been used both in Faddeev type of calculations[5, 6] and in more phenomenological treatments based on R-matrix[7, 8].

In particular, as far as this phenomenological treatment is concerned, we have used for the elastic reaction (1) an R-matrix analysis of the phase shifts fitted to the measured cross sections. The phase shifts analysis was performed using the eigenphase shift parametrization[7], i.e.

$$U^J_{\ell, \ell} = e^{2i\delta^J_\ell}$$

for the diagonal matrix elements, and allowing a mixing for the $J^\pi = 1^+$

$$U^1_{0, 0} = e^{2i\delta^1_\alpha} \cos^2 \varepsilon^1 + e^{2i\delta^1_\beta} \sin^2 \varepsilon^1 ,$$

$$U^1_{2, 2} = e^{2i\delta^1_\alpha} \sin^2 \varepsilon^1 + e^{2i\delta^1_\beta} \cos^2 \varepsilon^1 ,$$

$$U^1_{0, 2} = U^1_{2, 0} = \frac{1}{2} \sin(2\,\varepsilon^1) \left[e^{2i\delta^1_\alpha} - e^{2i\delta^1_\beta} \right] .$$

In Fig. 1 the results of the phase shifts analysis is shown together with the predictions from Faddeev calculations. The results of such a comparison indicates a discrepancy for the 1^+ complex (δ^1_α, δ^1_β, ε^1) between theoretical predictions and "experimental" phase shifts. In particular the imaginary part of δ^1_α shows a possible theoretical overestimate of the break-up cross sections.

In Fig. 2 the value of $\left| U^1_{0, 2} \right|$ as a function of the α incident energy is compared with predictions from Faddeev calculations[5] and resonanting group estimates[9]. The role of the α-d tensor interaction seems to be less relevant than theoretically estimated.

The phenomenological treatment for the breakup reaction is based mainly on the investigation of the Final State Interaction (FSI) regions (i.e. αn FSI corresponding to $^5\text{He}_{gs}$ formation[2] ; αp FSI corresponding to $^5\text{Li}_{gs}$ formation ; np FSI[3] corresponding to the produc
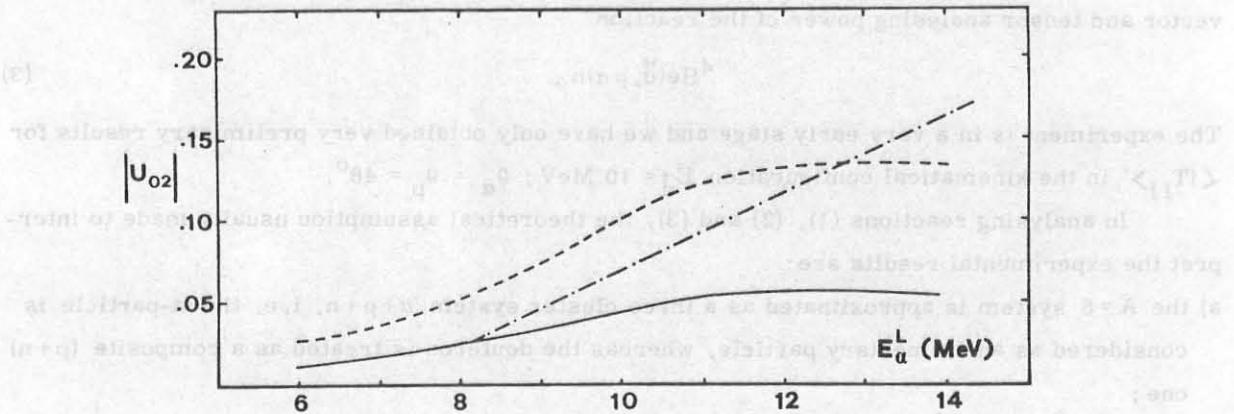
FIG. 2 - Absolute value of the off-diagonal matrix element for the $J = 1^+$ complex. Continuous line: evaluated from phase shifts of ref.(1); dashed line: calculations[1,5] based on Faddeev equations; dashed dotted line: results from a resonating group estimate[9].

tion of a triplet deuteron or a singlet isospin forbidden deuteron[10]).

Starting from the expression for the differential cross sections:

$$\frac{d^3\sigma}{d\Omega_p d\Omega_\alpha dE_p} = \frac{2\pi}{\hbar c} \frac{1}{v} |M|^2 \varrho$$

(where v is the αd relative velocity and ϱ is the three body phase space factor), to take into account different FSI, a simple incoherent additive model was used for the squared matrix element

$$|M|^2 = \Sigma_n |M|_n^2$$

where n correspond to a quasi two body resonant channel.

E.g. for the αn (αp) case we have[8]

$$|M|_n^2 = |\Psi_d|^2 \sin^2(\varphi_n + \delta_n) \frac{F_{\ell_n}^2 + G_{\ell_n}^2}{k^2 a_n^2} f_n(\chi)$$

where δ_n is the resonant phase shift, $\hbar k$ is the αn (αp) relative momentum, F_ℓ and G_ℓ are the neutron (proton) wave functions, Ψ_d is the deuteron wave function, and $f_n(\chi)$ gives the $\underline{\alpha n}$ gular dependence.

In such an additive model a fit of some experimental results is shown in Fig. 3.

In Figs. 4-7 a comparison is made between experimental results of the breakup reaction (2) and predictions from Faddeev equations not including Coulomb effects. αn and αp FSI regions are rather well reproduced while discrepancies appear in the np FSI. Suggesting the importance of isospin breaking, possibly due to Coulomb effects[3].

We stress that in the theoretical treatment three body forces, which correspond to $\underline{ex}$ citations of α-particles (see Fig. 8), have been neglected. Evidence of these effects has been claimed in a recent experiment[12]; low energy can in fact favour a long interaction period and
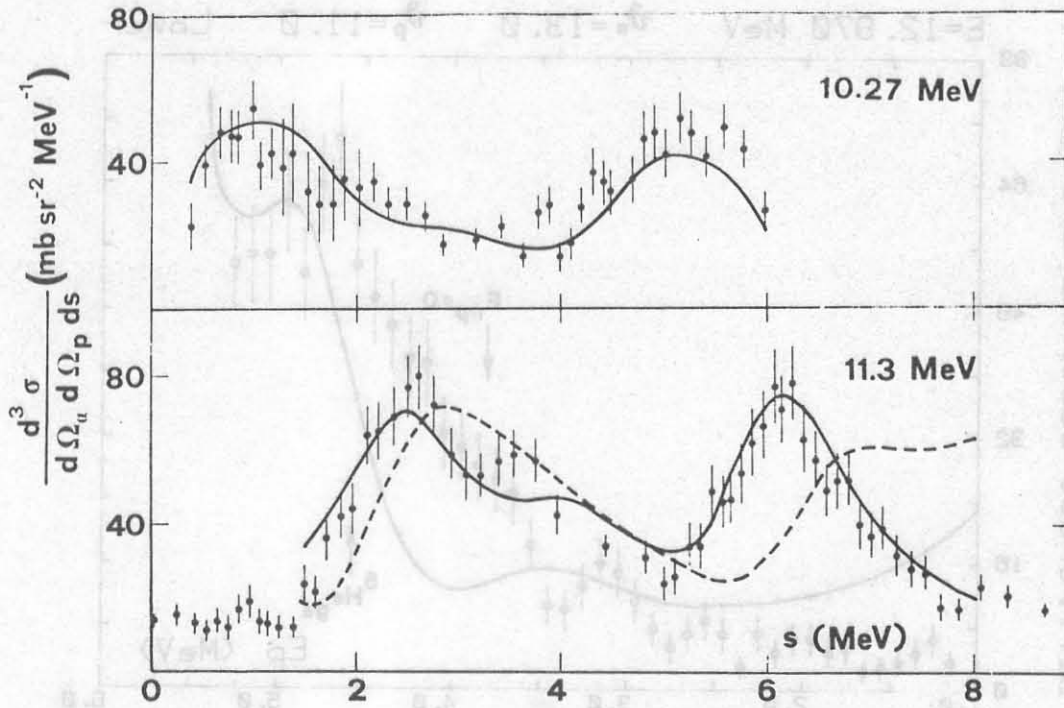
FIG. 3 - Differential cross sections versus arc length for $\theta_\alpha = 15^\circ$ and $\theta_p = 30^\circ$. The solid lines are the least square fits to the data with an incoherent addition of two-body interactions (average chi squared per point $\langle \chi^2_p \rangle = 1.5$). The dashed line is the calculation[6, 13] based on Faddeev equations multiplied by a normalization factor of 1.36.
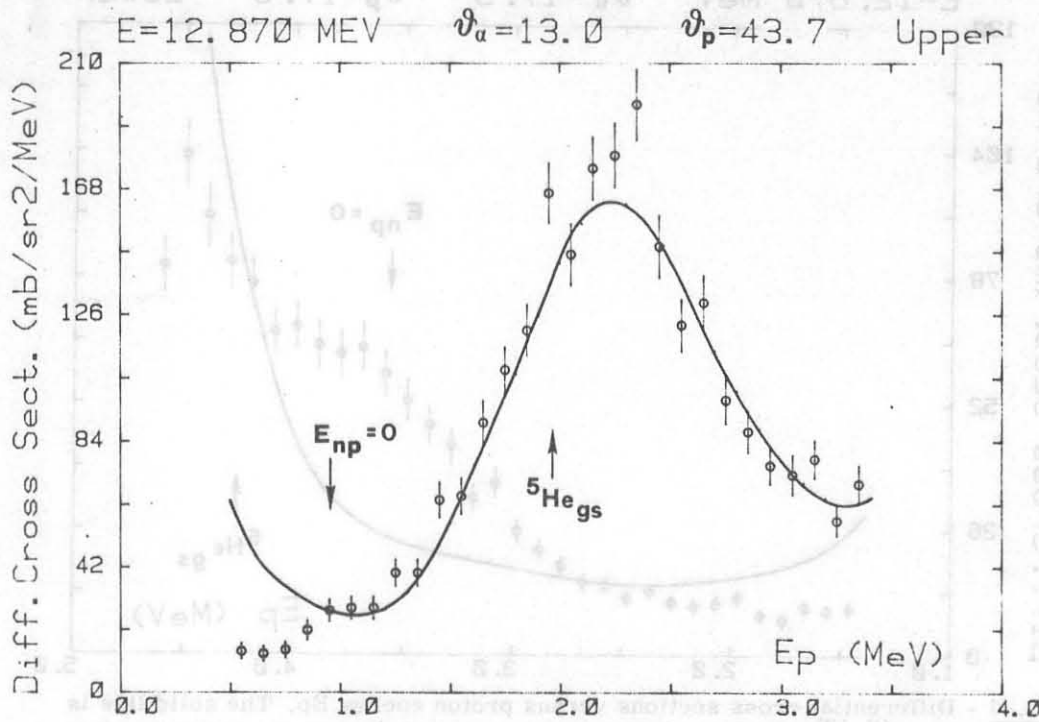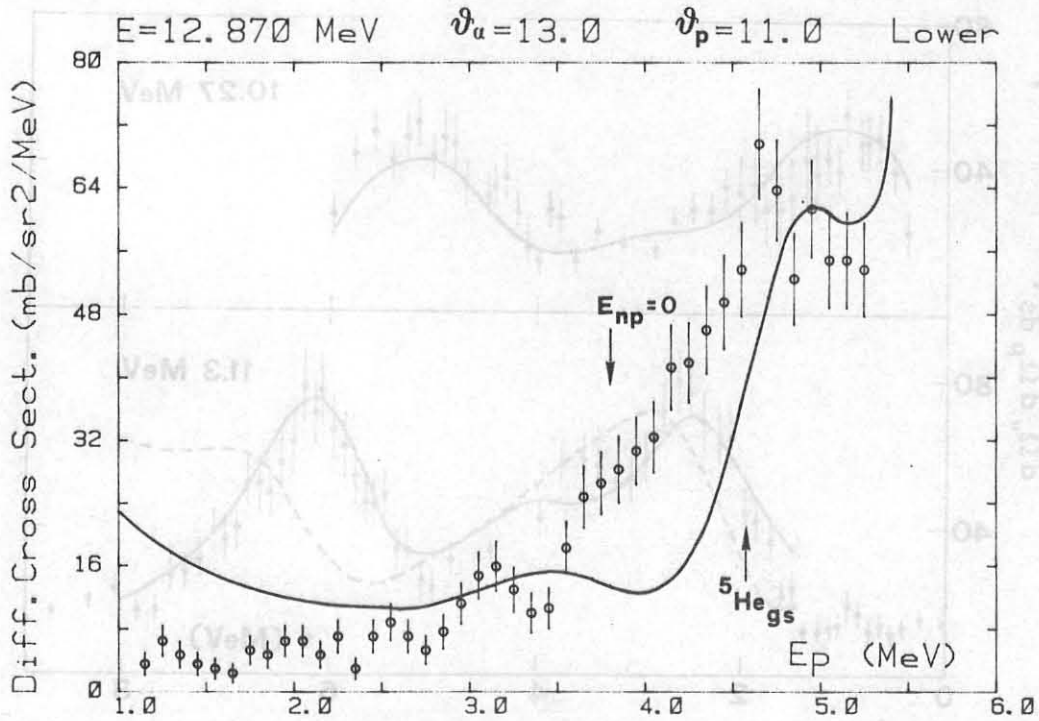

FIG. 4 - Differential cross sections versus proton energy Ep. The solid line is the calculations[6, 13] based on Faddeev equations without any normalization factor. The arrows indicate the values of Ep where the α-n (^{5}He), α-p (^{5}Li), n-p relative energies reach the values 0.9 MeV, 1.9 and 0 respectively.

- 6 -

E=12.870 MeV ϑ_α=13.0 ϑ_p=11.0 Lower

FIG. 5 - Differential cross sections versus proton energy Ep. The solid line is the calculation[6, 13] based on Faddeev equations without any normalization factor. The arrows indicate the values of Ep where the α-n (^{5}He), α-p (^{5}Li), n-p relative energies reach the values 0.9 MeV, 1.9 and 0 respectively.

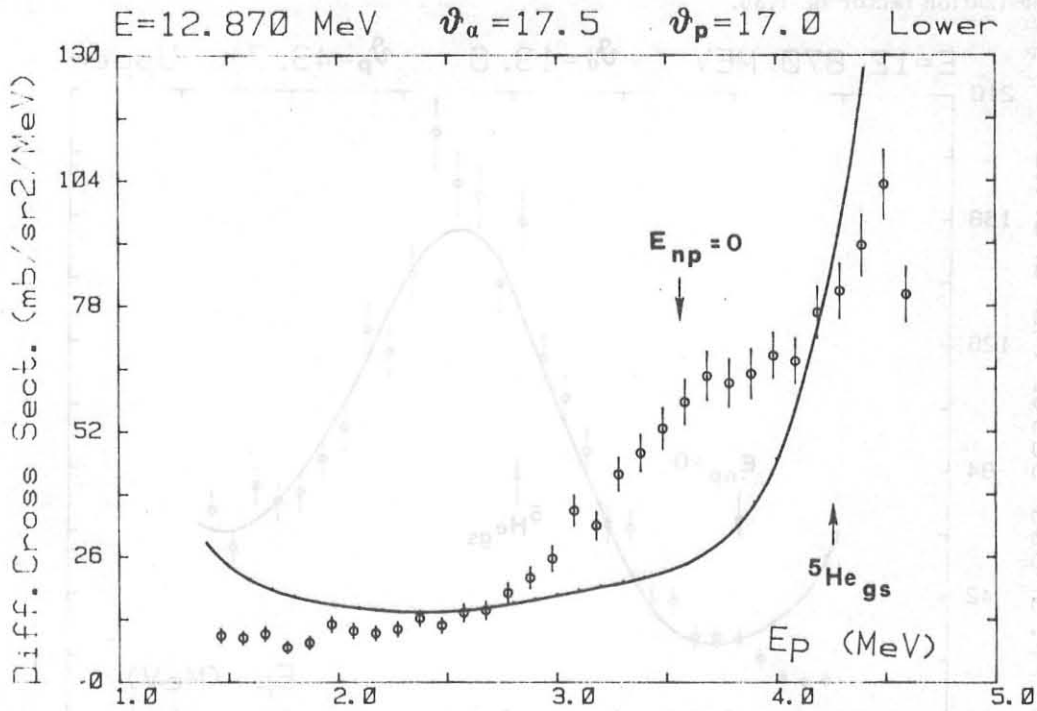E=12.870 MeV ϑ_α=17.5 ϑ_p=17.0 Lower

FIG. 6 - Differential cross sections versus proton energy Ep. The solid line is the calculation[6, 13] based on Faddeev equations without any normalization factor. The arrows indicate the values of Ep where the α-n (^{5}He), α-p (^{5}Li), n-p relative energies reach the values 0.9 MeV, 1.9 and 0 respectively.
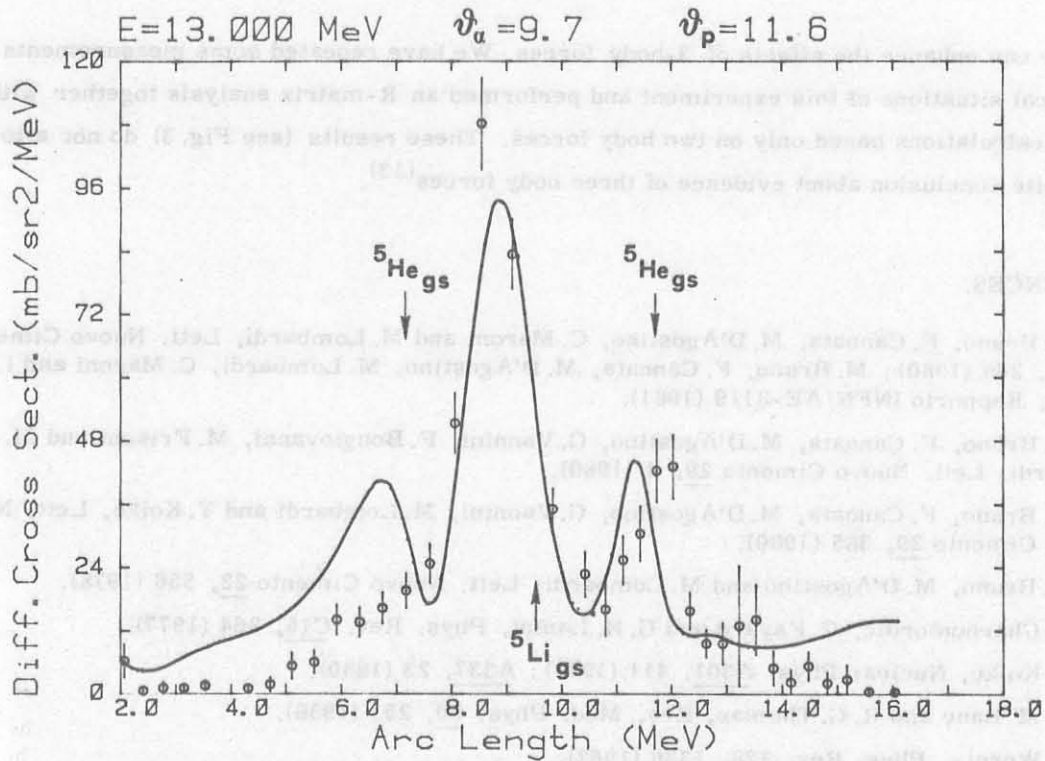
FIG. 7 - Differential cross sections versus arc length. The solid line is the calcu
lation[6, 13] based on Faddeev equations without any normalization factor. The
arrows indicate the values of Ep where the α-n(^{5}He), α-p(^{5}Li), n-p relative
energies reach the values 0.9 MeV, 1.9 and 0 respectively. In this kinematical
configuration the data of ref. (11) have a similar shape but for a scale factor 1.6
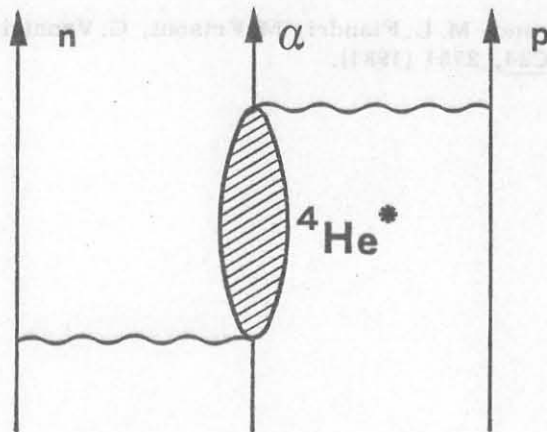larger.

FIG. 8 - A possible three-body force contribution
to the α-d interaction.

therefore can enhance the effects of 3-body forces. We have repeated some measurements in kinematical situations of this experiment and performed an R-matrix analysis together with Faddeev calculations based only on two body forces. These results (see Fig. 3) do not allow any definite conclusion about evidence of three body forces[13].

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