^{4}Li$_{\text{g.s.}}$ formation in the ^{3}He$+p+n$ reaction

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A measurement of the cross sections for the reaction $d+{}^3\text{He}\rightarrow{}^3\text{He}+p+n$ has been performed in a kinematical configuration allowing for the formation of the ^{4}Li ground state. The modifications of the resonance parameter due to the presence of the neutron have been investigated, together with the importance of a quasifree scattering mechanism. The resonance shift found is of the same order of magnitude as that predicted by recent calculations including three body forces. The width, however, is much smaller than suggested by an analysis of $p+{}^3$He elastic scattering.

The ^{4}Li$_{\text{g.s.}}$ system is known to belong to the same isospin multiplet as ^{4}H and ^{4}He* $T=1$ (Ref. 1) and its properties can be analyzed in the framework of microscopic few body calculations (Ref. 2). Recently, the role of ^{4}H in the final state interaction (FSI) of the reaction ^{7}Li$(n,\alpha)^3$Hn was investigated[3] and the possibility of ^{4}H formation in ^{6}Li(π^-,p) was pointed out.[4] In this note we present an experimental study of the ^{4}Li$_{\text{g.s.}}$ formation

$$d+{}^3\text{He}\rightarrow{}^4\text{Li}_{\text{g.s.}}+n \tag{1}$$

in the reaction

$$d+{}^3\text{He}\rightarrow{}^3\text{He}+p+n\ . \tag{2}$$

From a phenomenological point of view, the formation of ^{4}Li (Ref. 1) can proceed from the decay of an intermediate excited ^{5}Li via the emission of a neutron or from the direct breakup of the deuteron by ^{3}He, followed by its final state interaction with the proton. If highly excited ^{5}Li resonances do not exist, one expects the ^{3}He-p FSI mechanism to provide an adequate basis for a description of the main features of the experimental data of reactions (1) and (2). Of course this is even more true if, by an appropriate kinematical condition, one can avoid that ^{4}Li FSI overlaps with other FSI's like ^{3}He-n or n-p. Another mechanism which has to be controlled is the quasifree scattering (QFS), schematically shown in Fig. 1, which should also be well distinguishable from the ^{4}Li FSI. In order to achieve these goals, we have measured the differential cross sections of reaction (2) in a particular kinematical configuration where the ^{4}Li [cf. Eq. (1)] is well separated from other reaction mechanisms (see Fig. 2). The experiment was performed using a 23.08 MeV deuteron beam of the 16 MV XTU Tandem of the Laboratori Nationali di Legnaro. A special gas target allowed to determine absolute cross sections; a thin exit window has been used in order to minimize the energy loss of outgoing low energy ^{3}He. The detection system was set up such as to identify the particles and to measure their energies. A comprehensive description of the apparatus is given in Ref. 5. The observed events were projected onto the kinematical curve of Fig. 2 as described in Refs. 5 and 6. The absolute differential cross sections thus obtained are shown in Fig. 3; the typical uncertainty is of the order of 10%. Two peaks emerge distinctly: by kinematical considerations one can deduce that the peak at $s\simeq 6.3$ MeV is essentially a QFS since the neutron is emitted at 0° with half of the energy of the beam in the laboratory system. The importance of the quasifree mechanism has already been established in the companion reaction[7]

$$d+{}^3\text{He}\rightarrow{}^3\text{H}+p+p\ . \tag{3}$$

One can compare a calculation in the framework of the plane-wave impulse approximation (PWIA) to the experimental data around the quasifree peak.[7,8] Allowing a normalization coefficient N as a free parameter to be determined by a fitting procedure, we obtained a value $N=0.13$. For the cross sections of the reaction

$$p+{}^3\text{He}\rightarrow p+{}^3\text{He}\ , \tag{4}$$

the data of Ref. 9 were taken as input; for the deuteron the Hulthèn wave function was used, as given in Ref. 8. Although the multiple scattering effects are rather important in reducing the quasifree cross sections, it appears from the fit, presented in Fig. 3 as a dashed line, that the description is adequate to allow for a reliable extrapolation of the QFS mechanism to the region of the second peak. Therefore, we can discuss quantitatively the

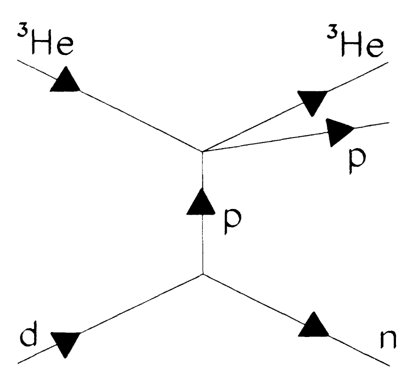

FIG. 1. Schematic picture of the quasifree scattering ($\theta_n=0°$ and $E_n=E_d/2$ in the laboratory frame).

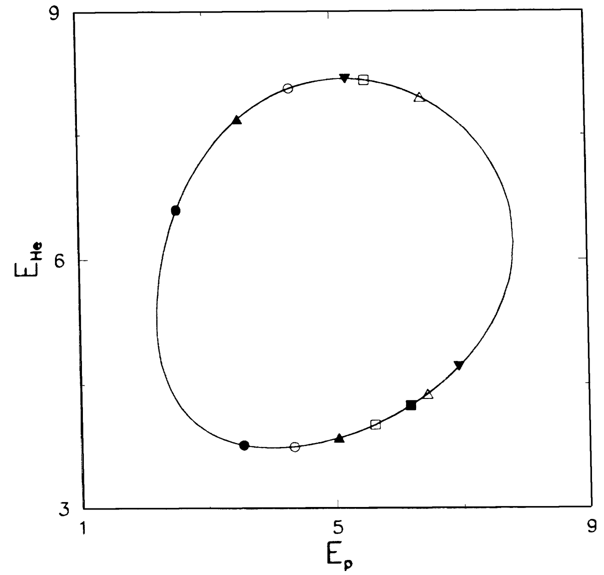

FIG. 2. Kinematically allowed curve for reaction (2): $\theta_p=65°$; $\theta_{^3He}=45°$. The arclength starts from E_{He} maximum, increasing clockwise. The various FSI's are indicated in the curve: (■) QFS; (●) $^4Li_{g.s.}$; (▲) $^4Li^*$ (1.4 MeV); (▼) $^4Li^{**}$ (3.2 MeV); (△) $^4He^*$ (25.5 MeV); (□) $^4He^*$ (26.4 MeV); (○) $^4He^*$ (27.4 MeV). The energies E_p and E_{He} are in MeV.

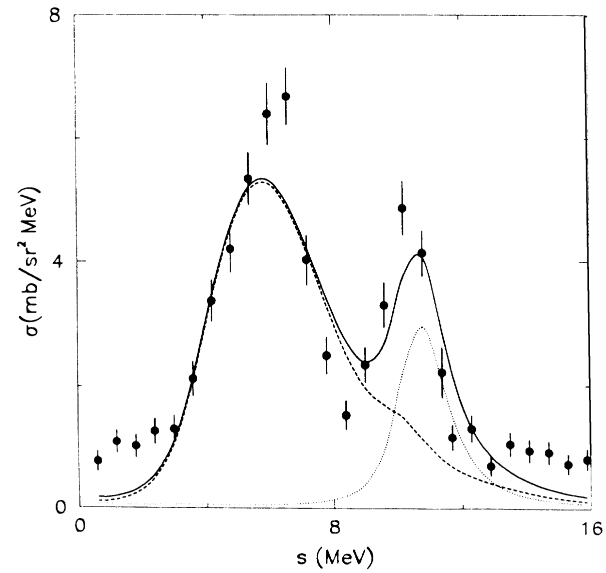

FIG. 3. Absolute differential cross sections for reaction (2), $\theta_p=65°$; $\theta_{^3He}=45°$. The continuous line is the result of the fitting procedure; the dashed line shows the QFS contribution and it is not shown when it overlaps with the continuous line; the dotted line is the contribution of $^4Li_{g.s}$ as obtained from the fit.

second peak which, by kinematical considerations, can be associated to the $^4Li_{g.s.}$ production. We have performed a fit adding incoherently the QFS (as described earlier) and the $^4Li_{g.s.}$, treating the latter as a simple Breit-Wigner, where the resonance energy, the width, and the strength are taken as free parameters. The results of the fit, shown as a continuous line in Fig. 3, give a resonance energy $E_r=3.3$ MeV instead of 4.7 MeV and a width $\Gamma=0.8$ MeV. The downward shift of the resonance energy is to be interpreted as a three-body effect induced by the third particle, i.e., the neutron. We also allowed for interferences, but the quality of the fit was not improved. We note that if we fit the same data with a constructive interference, we obtain a slight increase for the resonance energy, but the width is even further reduced. On the other side a destructive interference does not allow any reasonable fit.

In order to assess the stability of our results concerning the downward shift, we have included in the fit all the kinematically allowed ^4He and ^4Li excited states indicated in Fig. 2, adding them incoherently to the QFS and the $^4Li_{g.s.}$. The weights of all these contributions were treated as free parameters. The quality of the fit of the ^4Li peak does not change substantially and the weights of the additional mechanisms turn out to be rather small; we therefore conclude that the second peak of Fig. 3 provides (see dotted line) a rather clear indication that the $^4Li_{g.s.}$ resonance parameters can be drastically modified in the reaction involving three particles. In general, the five nucleon final state may influence the extraction of the $^4Li_{g.s.}$ parameters. It is interesting to recall that such a modification is necessarily expected within a formalism in which three-body forces are allowed,[10] although the resonance shift is certainly not a definite signature of three-body forces,[11] because our theoretical curves are based upon severe approximations. Typically, the contribution of three-body forces to the energies of $^4He^*$ excited states is found to be a couple of MeV.[10] Therefore, we expect in a more extended system, like the one which is formed in the intermediate step of reaction (1), i.e., ^5Li excited state, a somewhat smaller effect.

As a final comment, we would like to stress that the width we obtained for the $^4Li_{g.s.}$ is much smaller than the one obtained from an analysis of $p+{}^3He$ elastic scattering, however, it is compatible with an analysis of the $^4He(p,n)p\,^3He$ reaction[12].

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