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^{4}H and (n, αx) reactions on ^{6}Li and ^{7}Li

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The cross sections for the ^{6}Li(n, αx) and ^{7}Li(n, αx) reactions have been measured by the detection of α particles in coincidence with other charged particles (x). Prominent structures in the coincident α-particle energy spectra have been observed only in the case of ^{7}Li. They could be attributed to the processes involving the states of ^{4}H.

The four-nucleon system is the lightest few-nucleon system to exhibit resonances at low energies. The only particle stable state is the ground state of ^{4}He. There is now enough evidence showing that ^{4}H and ^{4}Li have only broad particle unstable states. However, the data on the positions and widths of these states have often been contradictory, especially in the case of ^{4}H.

The neutron total cross section for tritium shows a strong resonance behavior at incident neutron energies around 3.5 MeV.[1] A phase shift analysis[2] of older ^{3}H(n,n)^{3}H data indicated that the lowest $T=1$ levels of ^{4}H are broad P-wave triplet resonances having assignments of 2^- and 1^-, resonance energies of 3.4 and 5.1 MeV, and equal reduced widths of 5.5 MeV. However, this analysis was questioned by Morrow and Haeberli.[3] Recent microscopic calculations[4,5] predict broad overlapping resonances at low excitation energies in n+t system (i.e., low energies above the unbound n+t mass). On the other hand, the values of ^{4}H ground state energy as obtained from different ^{7}Li(π^-, tt)n reaction measurements[6-9] range from 0.3 MeV (Ref. 6) to 8 MeV (Ref. 8) in the excitation energy in n+t system. ^{4}H contributions were also observed in the following reactions: ^{6}Li(π^-,dt)n (Refs. 6–9), ^{4}He(π^-,γ)^{3}Hn (Ref. 10), ^{6}Li(^{6}Li,^{8}B)^{3}Hn (Ref. 11), and ^{7}Li(^{3}He,^{3}He^{3}He)^{3}Hn (Ref. 12). The results of these measurements also differ, which could be explained by the complexity of these processes and experimental difficulties. The only available data on ^{3}H(d,p)^{3}Hn and ^{3}H(t,d)^{3}Hn reactions[13] show a broad structure in the energy spectra, which could be attributed to the ^{4}H ground state. In some measurements[7,9] observation of ^{4}H excited states was also claimed.

Because of the special interest in the level structure of four nucleon systems, which is proving ground for different few-nucleon theories, it is important to get consistent data on ^{4}H states. One of a few relatively simple reactions for this study is the ^{7}Li(n,α)^{3}Hn reaction. Due to the α-t cluster structure of ^{7}Li one could expect to observe ^{4}H contributions in α-particle energy spectra at very forward (α-particle knockout) and very backward angles (triton pickup) for incident neutron energies above 10 MeV. However, measurements of the same spectra from ^{6}Li targets can be used for different calibration and background test purposes. One does not expect any structures in the continuum part of the α-particle energy spectra from ^{6}Li(n,α) reactions, because there are no triton excited states at low energies. However, no α-particle spectra from ^{6}Li and ^{7}Li targets from these angular regions could be found in the literature. The lack of data may be due to the difficulties in the preparation of pure lithium targets and to the unfavorable Q values of these reactions with respect to (n,α) reaction Q values for possible target contaminants and suitable backings.

In our experiment these difficulties were avoided by coincident detection of two outgoing charged particles. The experimental setup used in the measurements is shown in Fig. 1. 14.6 MeV neutrons were used to irradiate lithium targets. Charged particle products were detected in coincidence, using a counter telescope consisting of three proportional counters (ΔE_i) and a solid state detector (E).[14] α particles were detected and identified using ΔE_2, ΔE_3, and E counters, while other charged particles were detected in a ΔE_1 counter. The ^{6}Li(n,α)^{3}H reaction was used as a calibration standard for pulses of the tritons detected in ΔE_1 counter. The proportional counters were filled with pure hydrogen ($p=10$ kPa) to avoid (n,α) reactions on counter gases. Isotopically enriched targets were made from different compounds (e.g., LiF, LiH) by evaporation or by sedimentation onto thin gold or nickel foils. The foil thicknesses were chosen in such a way to stop heavy particle recoils and to allow higher energy (>0.8 MeV) tritons to reach the ΔE_1 counter. Special care was taken to maintain the same conditions for both the ^{6}Li and ^{7}Li targets during their preparation, storage, and use in the measurements.

Many different coincident α-particle energy spectra were collected. Figure 2 shows typical spectra (background subtracted) measured at $\theta_\alpha=0°$. The vertical bars with horizontal arrows mark the maximum α-particle energies for different (n,αx) reactions. In the case of ^{6}Li, the sharp peak at higher energies corresponds to the two-body reaction ^{6}Li(n,α)^{3}H. The dashed curves correspond to the three-body phase space distribution as calculated by a Monte Carlo program. This calculation takes into account the an-

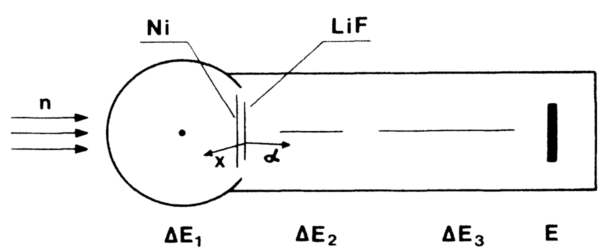

FIG. 1. Experimental setup.

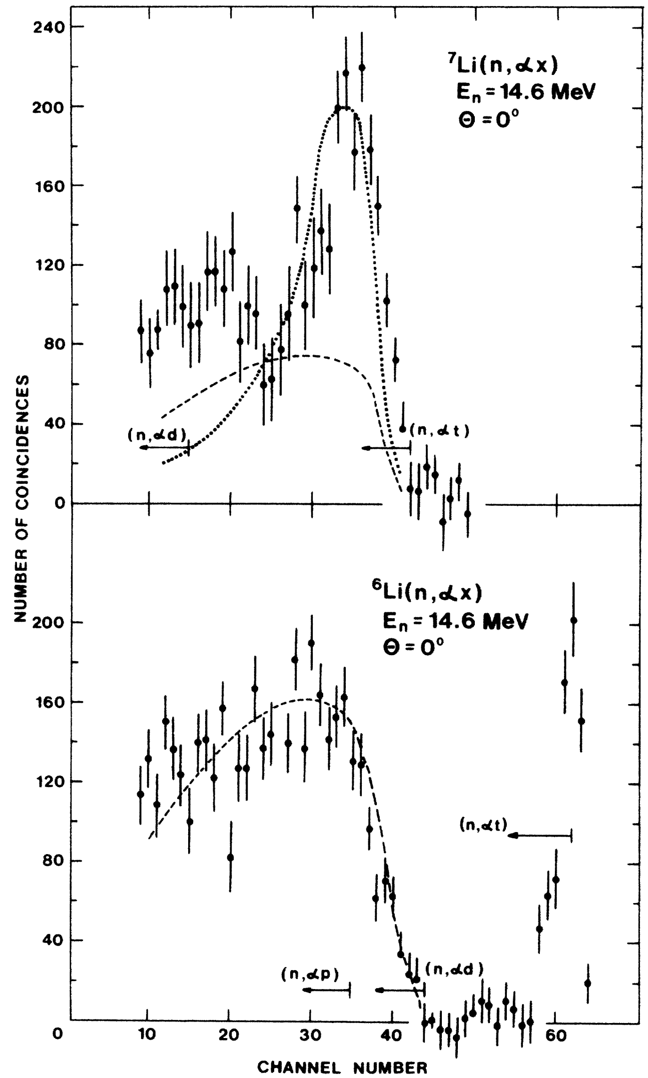

FIG. 2. Coincident α-particle spectra from ^{6}Li(n,αx) and ^{7}Li(n, αx) reactions. The dashed lines represent calculated three-body phase space distributions for the ^{6}Li(n,αd)n and ^{7}Li(n, αt)n reactions, respectively. The dotted line shows the calculated ^{7}Li(n, α_0)^{4}H reaction contribution (E_r = 2.7 MeV, γ^2 = 2.3 MeV for ^{4}H ground state).

gular acceptance of the detectors as well as the energy losses of detected particles. In the case of ^{6}Li there is no structure in the continuum part of the spectrum (no triton excited states). However, in the case of ^{7}Li, there are significant departures from this distribution. Because of that, the ^{7}Li(n, α_0)^{4}H reaction contribution was calculated with the same Monte Carlo program imposing additionally a resonance of the form

$$f(E) \propto P_c\gamma^4/[(E-E_r)^2+(P_c\gamma^2)^2] \ ,$$

as it was done and explained in Ref. 9. P_c is the penetration factor, E_r is the resonance energy, and γ^2 is the reduced width. The values of the parameters were the same as in Ref. 9, i.e., E_r = 2.7 MeV, γ^2 = 2.3 MeV, and r = 4 fm. The dotted curve is the result of this calculation. It can be seen that the agreement in the higher energy part of the spectrum is satisfactory. Similar results were obtained for $\theta = 15°$.

The structure in the lower part of the spectrum falls in the region where the first excited state could be expected. However, due to possible contributions of the four-body reaction, ^{7}Li(n, αd)nn, and higher background in this region, it is not possible to make any definite conclusion on the first excited state involvement.

In summary, some structures were observed in the spectra of the ^{7}Li(n,αx) reaction, which could be attributed to the state(s) of ^{4}H. A calculation using ^{4}H ground state parameters (E_r = 2.7 MeV and γ^2 = 2.3 MeV) as obtained from the most complete study of the ^{7}Li(π^-,tt)n reaction,[9] fits satisfactorily the higher energy part of the spectra. However, a complete calculation taking into account all the processes involved (e.g., sequential processes through ^{5}He and ^{7}Li states) is needed to establish the significance of the contribution of ^{4}H states as well as the true values of their parameters. It would be highly desirable to perform kinematically complete experiments of other "simple" reactions [e.g., ^{3}H(d,tp)n and ^{3}H(t,td)n], which are the most suitable three-body processes to get data on ^{4}H states.

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