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THE (^{3}He,^{6}He) REACTION ON ^{6}Li AND ^{7}Li[†]

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Energy spectra of ^{6}He from the reactions ^{6}Li(^{3}He,^{6}He)3p and ^{7}Li(^{3}He,^{6}He)^{4}Li have been measured at 14.1° for a ^{3}He bombarding energy of 53.2 MeV. No evidence is found either for a T = 3/2 state in the triproton system or for a T = 2 state in ^{4}Li.

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Current interest in the level structure of three-nucleon [1] and four-nucleon [2] nuclei has prompted an investigation of the systems (3p) and ^{4}Li by means of the (^{3}He,^{6}He) reaction on ^{6}Li and ^{7}Li. In spite of its low yield [$d\sigma/d\Omega \sim$ (1-4) μb/sr at forward angles], the (^{3}He,^{6}He) reaction has been used previously [3] to determine the masses of several proton-rich nuclei (e.g., ^{7}B and ^{9}C). To the extent that the (^{3}He,^{6}He) reaction on ^{6}Li can be considered a direct three-neutron transfer, it should selectively populate the lowest state in the (3p) system since the protons in the target already have the appropriate shell-model configuration. A similar argument applies to the formation of the lowest T = 2 state in ^{4}Li.

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Previous investigations of the (3p) system have been made with the ^{3}He(^{3}He,t)3p and ^{3}He(p,n)3p reactions. Measurements of triton spectra from the ^{3}He(^{3}He,t)3p reaction at 18-20 MeV [4] suggest a sequential decay through the 20 MeV level in ^{4}He. At 44 MeV [5] departures of the triton spectra from four-body phase space can be accounted for by including the Coulomb interaction between the triton and the (3p) system. Neutron spectra from the ^{3}He(p,n)3p reaction at 25 MeV [6] indicate a slight deviation from four-body phase space. This has been tentatively explained as due to a $^1S_0$ final-state interaction between two of the three protons. At 50 MeV [7] the departure from phase space is considerably more pronounced and has been interpreted in terms of a T = 3/2 state in the (3p) system at Ex(3p) = (9±1) MeV with a width Γ = (10.5±1) MeV.

There have been several previous attempts to locate the T = 2 state in ^{4}Li. A careful search [8] of the π^- decay modes of the hypernucleus $^4_\Lambda$He (e.g., $^4_\Lambda\text{He} \rightarrow \pi^- + p + {}^3\text{He}$) shows no evidence for sharp resonances in ^{4}Li. In a high resolution measurement of the excitation function for p + ^{3}He elastic scattering at backward angles [9], there is no indication of a narrow level in ^{4}Li for excitations above the p + ^{3}He threshold between 9.5 and 11.6 MeV. Finally, in a recent study of the ^{7}Li(^{3}He,^{6}He)^{4}Li reaction at 37 MeV and 20° [10] no evidence was found for a sharp state in ^{4}Li up to an excitation of about 12 MeV.

In the present experiment a 53.2 MeV ^{3}He beam from the Berkeley 88-inch cyclotron was used to bombard self-supporting enriched ^{6}Li and ^{7}Li targets (≈200 μg/cm^2). The resultant ^{6}He nuclei were identified using a three-counter particle identification system that has been described previously [3,11]. Two similar four-counter telescopes consisting of 130μ ΔE_2, 109μ ΔE_1, 305μ E, and 500μ E-reject counters were operated at equal angles on opposite sides of the beam. A typical particle-identifier spectrum for one of these telescopes is shown in fig. 1. The $^{11}B(^3He,^6He)^8B$ reaction was used to provide an absolute energy calibration and peak positions of the ^6Li reaction products were monitored periodically to verify that no gain shifts occurred during the ~25 hr bombardment of each target.

The ^6He energy spectrum at 14.1° from the reaction $^6Li(^3He,^6He)3p$ is shown in fig. 2(a). The spectrum covers ^6He energies between 26 and 40 MeV and allows an investigation of the residual (3p) system from the threshold ($Q = -10.45$ MeV) to an excitation of about 12 MeV. For this spectrum, three-channel sums were made of the original data consistent with an overall resolution of 225 keV. The spectrum shape is remarkably smooth and is quite similar to the solid curve which gives the phase space distribution for the four-particle final-state, ^6He + 3p, modified to include the Coulomb interaction between the ^6He and the (3p) system [12]. Similar results were obtained in a run of shorter duration at 11.7°.

The ^6He energy spectrum at 14.1° from the reaction $^7Li(^3He,^6He)^4Li$ is shown in fig. 2(b). Again, three-channel sums were made of the original data, in this case consistent with an overall resolution of 175 keV. The spectrum covers an excitation in ^4Li of 15 MeV relative to the p + ^3He threshold ($Q = -9.98$ MeV). In this range no evidence is seen for a narrow state in ^4Li. It is clear, however, that if the order-of-magnitude estimates of a width of 10 keV for a T = 2 level in ^4Li at 10.6 MeV [9] are correct, its presence could be washed out by the present resolution in view of the apparently large contributions to the cross section from the three-, four-, and five-body continuum states. The relatively sharp rise of the spectrum between 0 and 3.5 MeV excitation in the ($p+{}^3He$) system is similar to that seen at forward angles in the ${}^6Li(p,t){}^4Li$ reaction [13] and is presumably due to a p-wave p-${}^3He$ final-state interaction corresponding to the low-lying, broad, T = 1 states in ${}^4Li$ [2]. A more detailed comparison indicates that this feature is considerably less prominent in the ${}^7Li({}^3He,{}^6He){}^4Li$ reaction. This raises the question of whether the (${}^3He,{}^6He$) reaction mechanism is selective of the simple configurations corresponding to higher isospin states, particularly in the very light nuclei where contributions from the multi-particle continuum states are known to be large. At present there is insufficient data in the form of angular distributions for (${}^3He,{}^6He$) reactions to test the three-neutron transfer mechanism.

In summary, ${}^6He$ energy spectra from the reactions ${}^6Li({}^3He,{}^6He)3p$ and ${}^7Li({}^3He,{}^6He){}^4Li$ have been measured at a ${}^3He$ energy of 53.2 MeV and 14.1°. In the former reaction the spectrum shape has the form of four-body phase space and no evidence is found for states in the (3p) system up to an excitation of 12 MeV. In the latter reaction no evidence is found for a narrow T = 2 state in ${}^4Li$ up to an excitation of 15 MeV.

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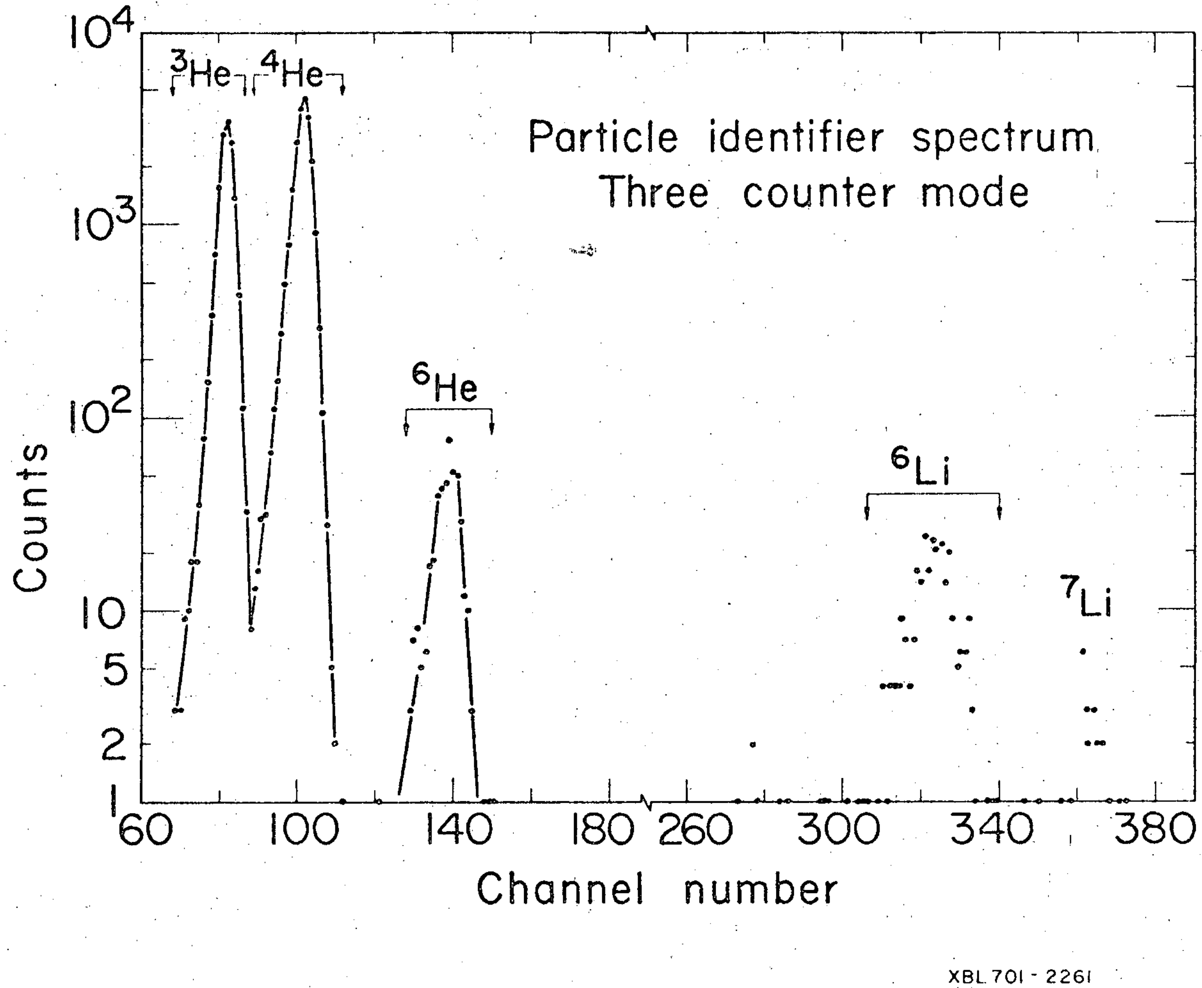
Figure Captions

Fig. 1. A typical three-counter particle identification spectrum for one of the counter telescopes showing the window for accepted ^{6}He events. Note the break in the horizontal scale between the Z = 2 and Z = 3 nuclei. The Z = 3 events are for calibration purposes and represent a smaller total charge.

Fig. 2(a). The ^{6}He energy spectrum from the $^{6}Li(^{3}He,^{6}He)3p$ reaction for one of the telescopes at 14.1° (lab). The scale at the top of the figure gives the excitation in the residual (3p) system. The solid curve represents the four-body phase space distribution described in the text.

Fig. 2(b). The ^{6}He energy spectrum from the $^{7}Li(^{3}He,^{6}He)^{4}Li$ reaction for one of the telescopes at 14.1° (lab). Arrows mark the thresholds for the p + ^{3}He, 2p + d, and 3p + n final states. The scale at the top gives the excitation in ^{4}Li relative to the p + ^{3}He threshold.



Particle identifier spectrum
Three counter mode
^{3}He
^{4}He
^{6}He
^{6}Li
^{7}Li
Counts
Channel number
10^4
10^3
10^2
10
5
2
1
60
100
140
180
260
300
340
380
XBL 701 - 2261

Fig. 1.

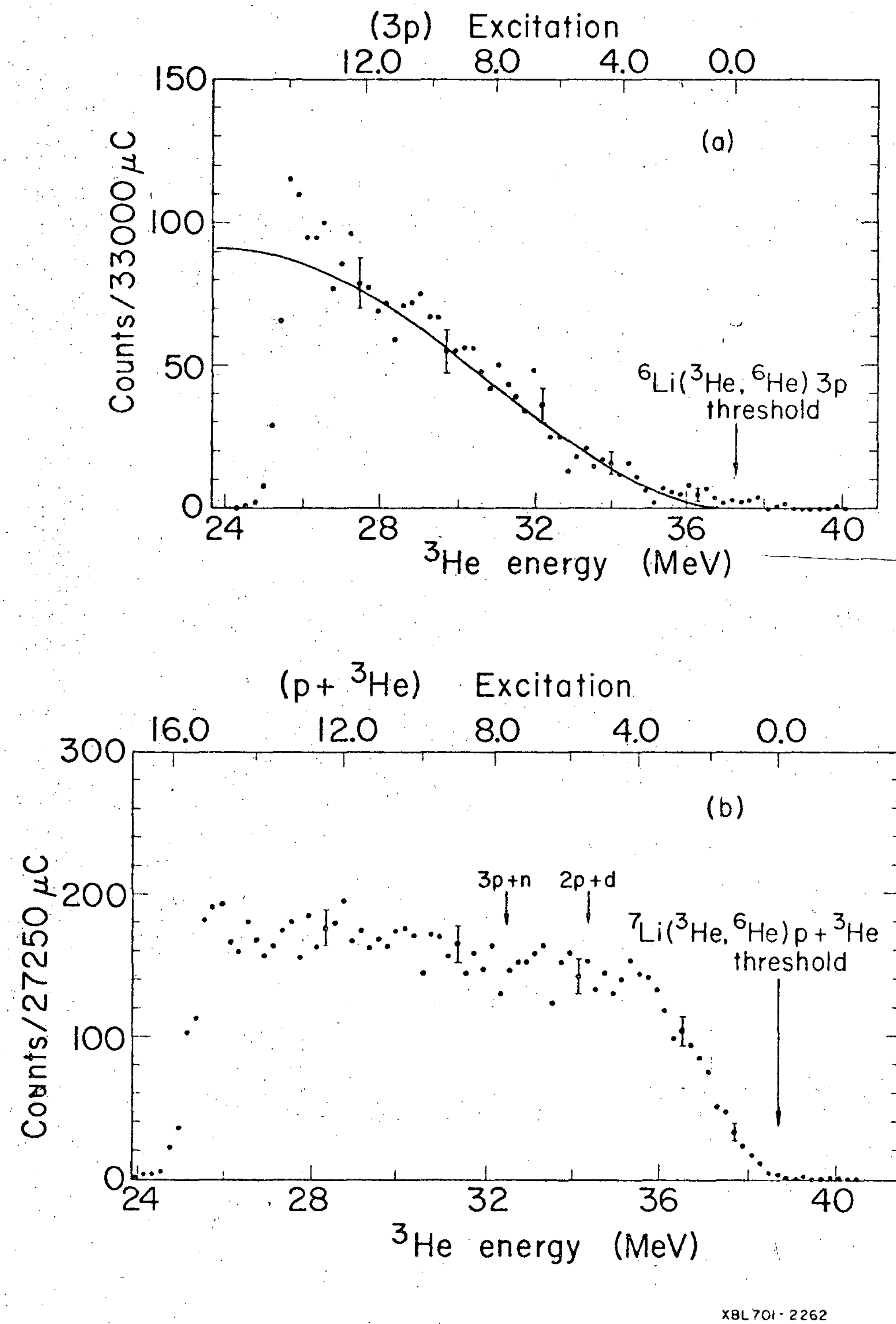

(3p) Excitation
12.0
8.0
4.0
0.0
150
100
50
0
Counts/33000 μC
(a)
6Li(3He, 6He) 3p
threshold
24
28
32
36
40
3He energy (MeV)
(p+ 3He) Excitation
16.0
12.0
8.0
4.0
0.0
300
200
100
0
Counts/27250 μC
(b)
3p+n
2p+d
7Li(3He, 6He) p + 3He
threshold
24
28
32
36
40
3He energy (MeV)
XBL 701-2262

Fig. 2.