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Publication Date

1974-09-01

Submitted to Physics Letters

LBL-3407
Preprint c.2

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September, 1974

Prepared for the U. S. Atomic Energy Commission
under Contract W-7405-ENG-48

^{7}Li + ^{7}Li REACTION STUDIES LEADING TO MULTI-NEUTRON FINAL STATES*

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September 1974

Boron and carbon reaction products have been observed in the bombardment of ^{7}Li by 79.6 MeV ^{7}Li. Comparisons of the ^{7}Li(^{7}Li,^{11}B)t and ^{7}Li(^{7}Li,^{11}C)3n channels and a study of the ^{7}Li(^{7}Li,^{10}C)4n reaction are presented.

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Although there has been extensive historical interest in questions of the possible stability of ^{3}n or ^{4}n, and of the location of unbound resonances in these systems, no bound states nor uncontroversial multi-neutron resonance effects have so far been established in either of these systems [see ref. [1] for a review of the 3n system; ref. [2], for the 4n]. Nonetheless, since certain heavy-ion reactions observing neutron-deficient reaction products afford a new look at these (and other [3]) multi-neutron final states, we have investigated one of the simplest of these systems, that of ^{7}Li + ^{7}Li → ^{12}C + 2n, ^{11}C + 3n, and ^{10}C + 4n. By also measuring the energy spectra and cross-sections of the boron isotopes in the better-established ^{12}B + d, ^{11}B + t and ^{10}B + ^{4}H

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*Work performed under the auspices of the U. S. Atomic Energy Commission.

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channels (but ones in which the light product nuclei have lower T_Z), one can hope to obtain some criteria by which to evaluate the yield in the carbon exit channels. Four of these reactions are discussed below; unfortunately, reactions on target contaminants precluded useful analysis of the ^{7}Li(^{7}Li,^{12}C)2n and ^{7}Li(^{7}Li,^{10}B)^{4}H results.

A beam of 79.6 MeV $^7Li^{+2}$ (~ 150 nA) from the Lawrence Berkeley Laboratory 88-inch cyclotron was used to bombard a 110 μgm/cm^2 ^{7}Li target. Reaction products were observed in two similar counter telescope systems placed at opposite sides of the beam. The data reported below came from the system placed at 7.4° (lab) with a 0.086 msr solid angle; it consisted of two transmission (ΔE) detectors, 18 and 14μm thick (the first with subnanosecond pile-up rejection [4]), a 190μm E detector, and a reject detector. Although equivalent results were obtained with the second system, which was placed at 9.6°, they were of poorer quality. Other experimental details were similar to those described previously [5]; a comparison of two particle identification signals was employed to reduce background, with a stringent comparison rejecting ~ 50% of the events traversing the telescope. Electronic and beam energy stability were monitored continuously, and the absolute beam energy was determined using a precision analyzing magnet.

Figure 1 presents particle identification spectra from ^{7}Li bombardment of ^{7}Li and ^{16}O (as SiO_2) targets. Since reactions on carbon and oxygen were a severe background problem, the latter spectrum is shown to permit comparison of relative isotopic yields from one of the major target contaminants. As can be seen from the figure, ^{11}C, ^{11}B and ^{12}B were relatively strongly produced in the ^{7}Li + ^{7}Li reaction. This high ^{11}C, but low ^{10}C, yield from ^{7}Li led to poor

^{10}C - ^{11}C separation, so that only those ^{10}C events whose particle identification signal fell in the lower half of its nominal spectral position were accepted for energy analysis.

The energy spectrum of the ^{7}Li(^{7}Li,^{12}B)d reaction is shown in fig. 2. Moderate population of the (unresolved) bound states of ^{12}B can be seen in this spectrum, with a composite cross-section of 4 μb/sr c.m. Experimental observation of the strength of the two-neutron final state interaction in the ^{7}Li(^{7}Li,^{12}C)2n data would be of great interest, but, as noted above, could not be observed due to interference by contaminant reactions.

Results from the ^{7}Li(^{7}Li,^{11}B)t and ^{7}Li(^{7}Li,^{11}C)3n reactions are compared in fig. 3(a) and 3(b-c), respectively. Transitions to a number of the bound ^{11}B final states can be seen which are substantially stronger than those in the ^{12}B + d data; in particular the ground state transition possesses a cross section of 23 μb/sr c.m. However, the ^{7}Li(^{7}Li,^{11}C)3n data per se in figs. 3(b) and 3(c) present no discernible structure. At this small forward angle the ^{11}C energy region that would correspond to a bound 3n system is free from reactions on target contaminants, and an upper limit of 70 nb/sr c.m. can be set for production of a bound ^{3}n. Two imperfect comparisons are available: this limit is a factor of ~ 300 less than the yield of the ^{11}B g.s. + t channel, and is a factor of ~ 12 less than the average yields of the ^{16}O(^{7}Li,^{11}C)^{12}B g.s. and ^{12}C(^{7}Li,^{11}C)^{8}Li g.s. reactions at forward angles (obtained from separate experiments). With regard to those transitions corresponding to an unbound 3n system, one sees in fig. 3(c) that the ^{11}C energy spectrum encompassing up to ~ 7 MeV excitation of three neutrons (before the bulk of the transitions from target contaminants begins) is well fit by four-body phase space.

Figure 4 presents an energy spectrum from the attempted three-proton transfer $^{7}Li(^{7}Li,^{10}C)4n$ reaction. Independent experiments on the $^{16}O(^{7}Li,^{10}C)^{13}B$ and $^{12}C(^{7}Li,^{10}C)^{9}Li$ reactions successfully observed the transfer of three protons with comparable ground state cross sections, averaging ~ 450 nb/sr c.m. Peaks from reactions on these target contaminants account for the observed structure in the 4n continuum region of fig. 4; the underlying background appears to be adequately fit by five-body phase space. Again, at this forward angle, contaminant reactions do not interfere in the region of the ^{10}C energy spectrum corresponding to transitions leading to a bound ^{4}n [the known mass of ^{8}He sets an upper limit to the total binding energy of ^{4}n (see ref. 2)]. The very minor background observed in this region arises from the ^{11}C "leak-through" remaining in this energy spectrum; however, it is still possible to set an upper limit of 30 nb/sr c.m. for the cross-section of this reaction leading to a bound 4n system. The only available comparison is to note that this limit is a factor of ~ 15 less than the yield of the observed three-proton transfer reactions on ^{12}C and ^{16}O.

These results set stringent limits [1,2] in failing to observe transitions to a bound ^{3}n or ^{4}n; further, no resonance structure was evident in these heavy-ion studies of the unbound 3n and 4n systems. Better data on the unbound 4n system (requiring rigid maintenance of the ^{7}Li target purity) would permit an interesting comparison with the $^{4}He(\pi^{-},\pi^{+})4n$ studies [6], in which a possible final state interaction is observed between one neutron pair in the exit channel. Clearly the above approach can also be extended to search for bound or unbound structure in higher neutron configurations.

REFERENCES

1. L. M. Delves and A. C. Phillips, Rev. Mod. Phys. 41 (1969) 497.
   G. Paić, Few Particle Problems in the Nuclear Interaction, ed. I. Slaus, S. A. Moszkowski, R. P. Haddock, and W. H. T. van Oers (North-Holland Publ. Co., Amsterdam, 1972) 539.
2. S. Fiarman and W. E. Meyerhof, Nucl. Phys. A206 (1973) 1.
   Yu. A. Batusov, Zh. Ganzorig, L. Gumnerova, I. V. Dudova, V. M. Sidorov, V. A. Khalkin and D. Chultem, Dubna preprint P1-7475 (1973).
3. J. Cerny, Reactions Between Complex Nuclei, Vol. 2. ed. R. L. Robinson, F. K. McGowan and J. B. Ball (North-Holland Publ. Co., Amsterdam, in press).
4. J. D. Bowman, A. M. Poskanzer, R. G. Korteling and G. W. Butler, Phys. Rev. C9 (1974) 836.
5. K. H. Wilcox, N. A. Jelley, G. J. Wozniak, R. B. Weisenmiller, H. L. Harney and J. Cerny, Phys. Rev. Lett. 30 (1973) 866.
6. F. Becker and Yu. A. Batusov, Rivista del Nuovo Cimento, Ser. 2, 1 (1971) 309, and references therein.

FIGURE CAPTIONS

Fig. 1. Particle identification spectra arising from ^{7}Li reactions on ^{7}Li and ^{16}O targets. The relative intensities of all boron peaks are low by a factor of ~ 0.25. Certain weak groups such as ^{14}B in the ^{7}Li + ^{7}Li data must arise from target contaminants.

Fig. 2. An energy spectrum from the ^{7}Li(^{7}Li,^{12}B)d reaction at 79.6 MeV and 7.4°. Dashed arrows denote the expected locations of the indicated transitions.

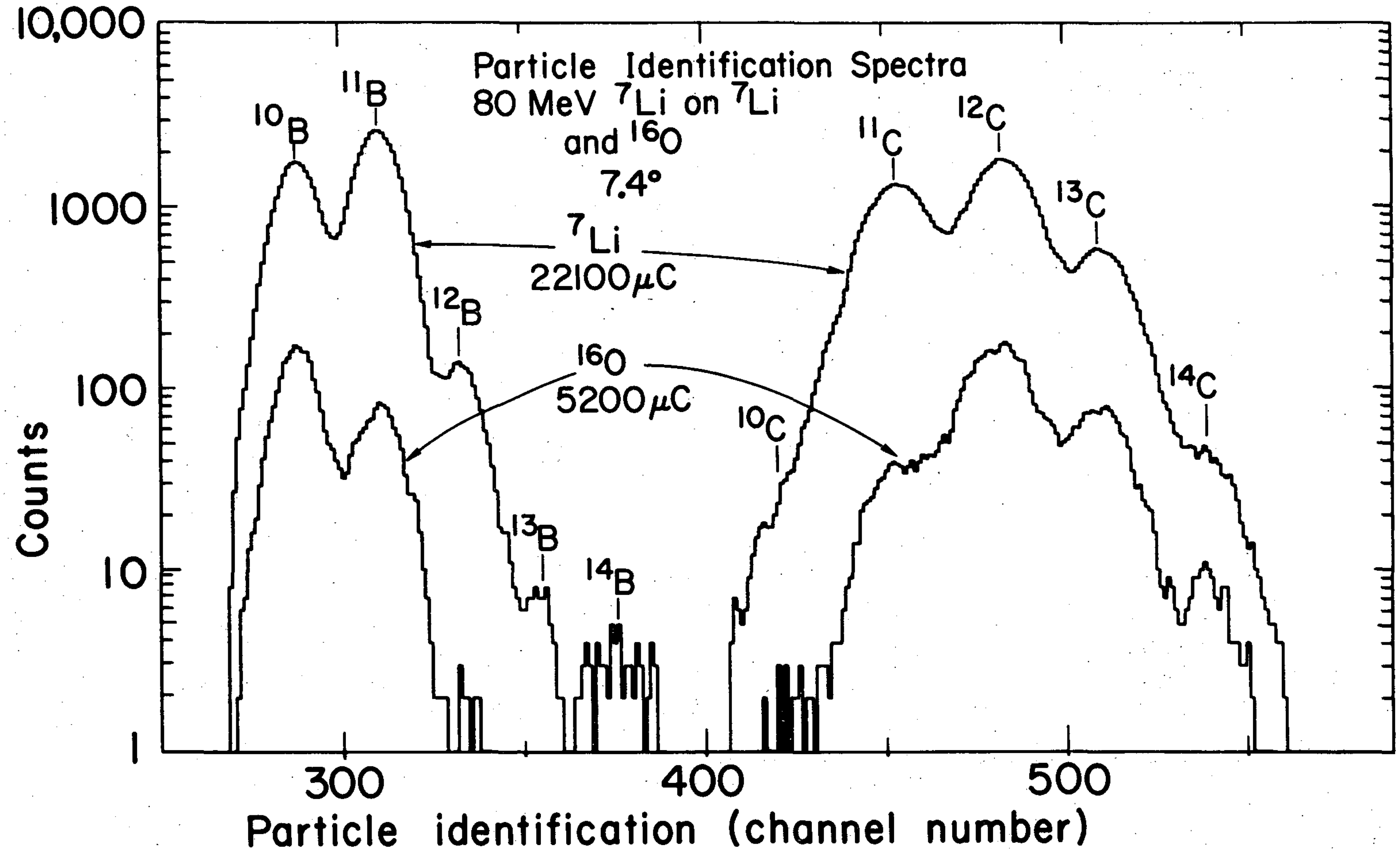
Fig. 3. Spectra from the ^{7}Li + ^{7}Li reaction at 79.6 MeV.

(a) ^{7}Li(^{7}Li,^{11}B)t. Dashed arrows denote the expected location of contaminant reactions.

(b) ^{7}Li(^{7}Li,^{11}C)3n. See (a). An arrow with an asterisk denotes the location of a known contaminant reaction. Also indicated is the ^{11}C energy that would correspond to transitions to a three neutron system with zero binding energy (B.E.).

(c) A detail of the high-energy part of (b).

Fig. 4. An energy spectrum from the ^{7}Li(^{7}Li,^{10}C)4n reaction at 79.6 MeV and 7.4°. Known contaminant reactions are indicated either explicitly or by an arrow with an asterisk.



XBL745-3203

Fig. 1

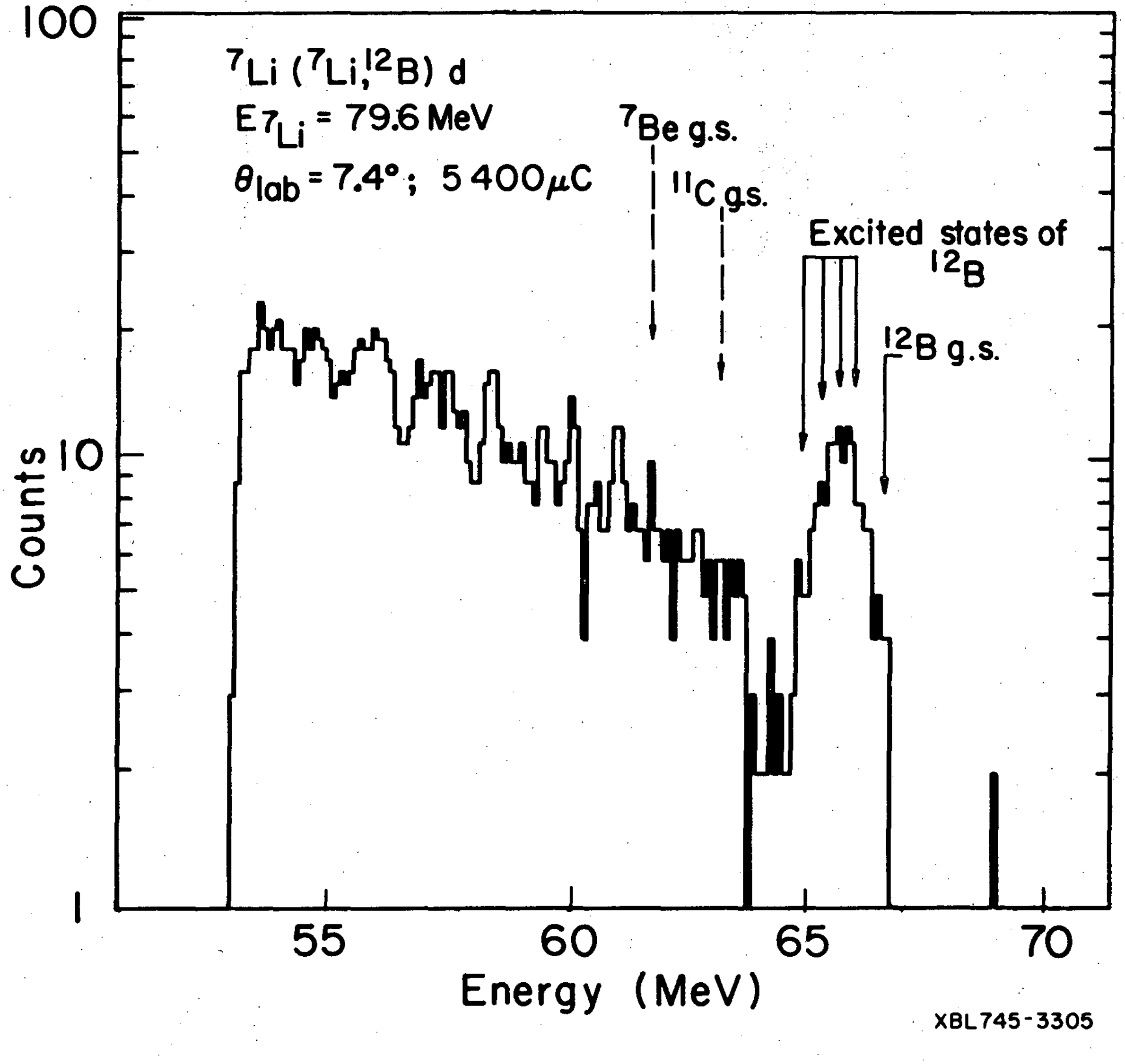

^{7}Li (^{7}Li,^{12}B) d
E$_{^7\text{Li}}$ = 79.6 MeV
θ_{lab} = 7.4°; 5400μC
^{7}Be g.s.
^{11}C g.s.
Excited states of ^{12}B
^{12}B g.s.
Counts
100
10
1
55
60
65
70
Energy (MeV)
XBL745-3305

Fig. 2

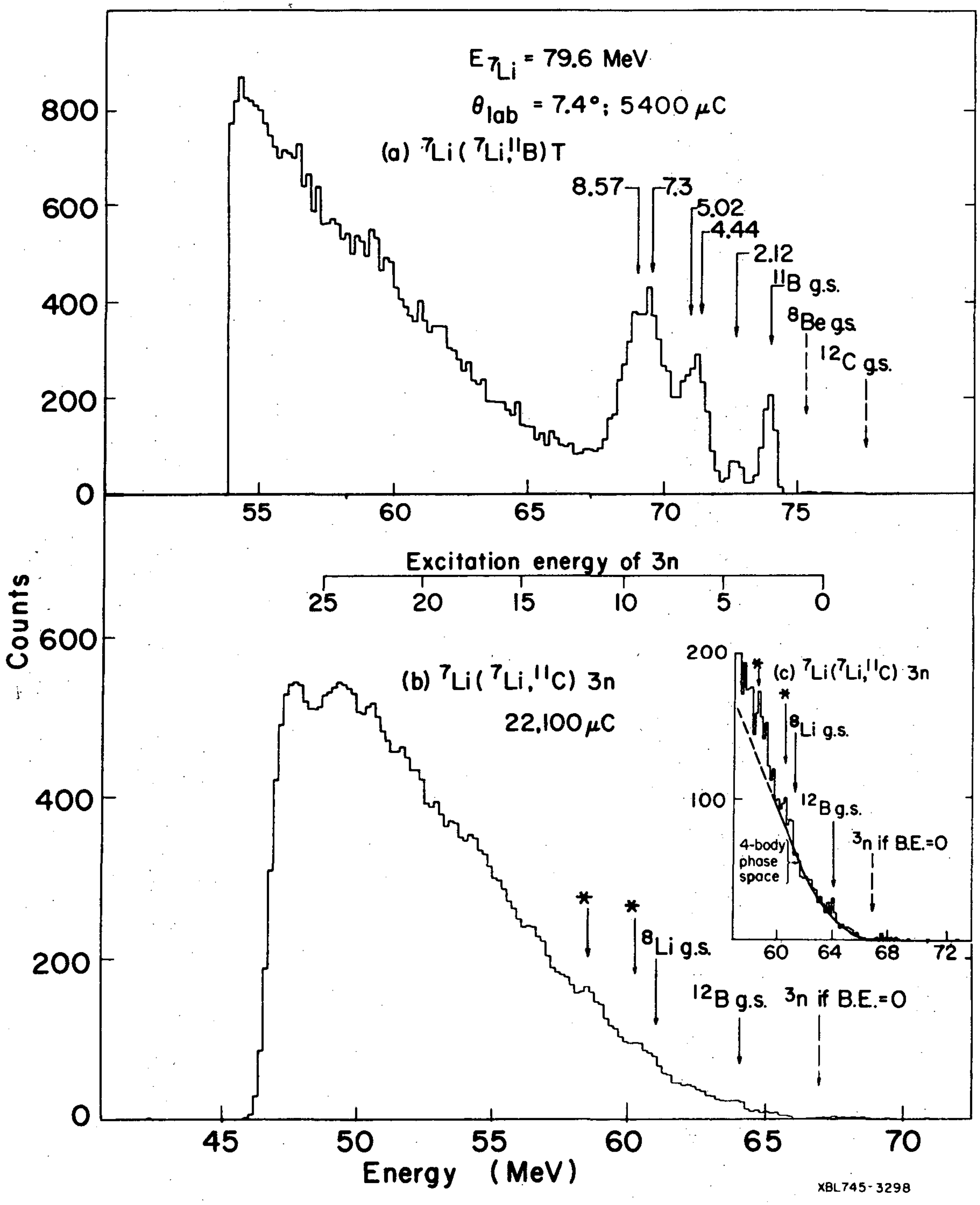

$E_{^7Li}$ = 79.6 MeV
θ_{lab} = 7.4°; 5400 μC
(a) ^{7}Li(^{7}Li,^{11}B)T
8.57
7.3
5.02
4.44
2.12
^{11}B g.s.
^{8}Be g.s.
^{12}C g.s.
800
600
400
200
0
55
60
65
70
75
Counts
Excitation energy of 3n
25
20
15
10
5
0
(b) ^{7}Li(^{7}Li,^{11}C) 3n
22,100 μC
*
*
^{8}Li g.s.
^{12}B g.s.
^{3}n if B.E.=0
(c) ^{7}Li(^{7}Li,^{11}C) 3n
^{8}Li g.s.
^{12}B g.s.
^{3}n if B.E.=0
4-body phase space
200
100
60
64
68
72
600
400
200
0
45
50
55
60
65
70
Energy (MeV)
XBL745-3298

Fig. 3

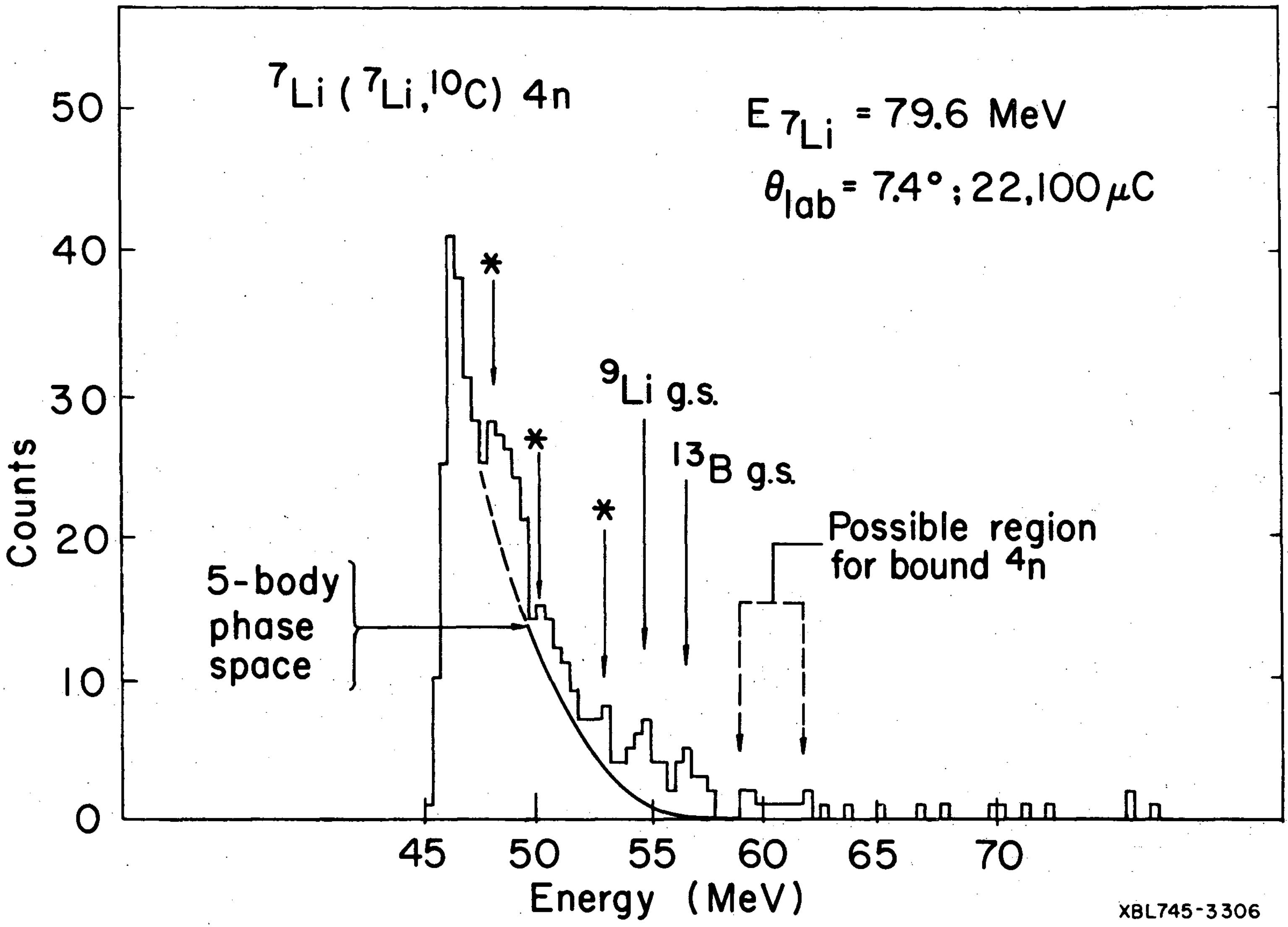

^{7}Li (^{7}Li,^{10}C) 4n
$E_{^7Li}$ = 79.6 MeV
θ_{lab} = 7.4° ; 22,100 μC
Counts
0
10
20
30
40
50
*
*
*
^{9}Li g.s.
^{13}B g.s.
Possible region for bound ^{4}n
5-body phase space
45
50
55
60
65
70
Energy (MeV)
XBL745-3306

Fig. 4

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