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THE OBSERVATION OF T = 3/2 LEVELS IN Li^7 - Be^7† AND THE UNCHARACTERIZED NUCLEI He^7, B^7 AND He^8

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The location and properties of the hitherto unestablished T = 3/2 levels in the $T_Z = \pm 1/2$ nuclei Li^7 and Be^7 are important nuclear structure information; in addition, the question of particle stability of the controversial nuclei He^7, B^7 and He^8 should be answerable by extrapolation from these T = 3/2 states.

As has previously been shown,[1-3] (p,t) and (p,He^3) reactions can be a valuable spectroscopic tool for locating states of high isospin in the residual nuclei. To investigate these mass seven nuclei, the reactions $Be^9(p,t)Be^7$ and $Be^9(p,He^3)Li^7$ were induced by 43.7 MeV protons from the Berkeley 88-inch cyclotron. Tritons and He^3 emitted from the 650 μg Be^9 target were detected by a (dE/dx) - E counter telescope which fed a particle identifier.[4] Figure 1 shows two typical spectra obtained at 32.5 degrees; the energy resolution averaged 170 keV for tritons and 200 keV for He^3.

One would in general expect the angular distributions of the T = 1/2 mirror states of Be^7 and Li^7 formed in these reactions to differ both in shape and magnitude. This arises since the (p,t) transitions occur predominantly by ^1S, T = 1 pick-up of two neutrons, while the (p,He^3) transitions can occur by pick-up of a proton-neutron pair in a predominant ^3S, T = 0 or ^1S, T = 1 configuration. Marked differences are in fact observed in the compared mirror angular distributions and are even apparent in Fig. 1.

However, transitions to T = 3/2 states in Li^7 and Be^7, assuming the charge independence of nuclear forces, proceed from identical initial to final states through only ^1S, T = 1 pick-up of the two nucleons; as such, identical cross sections are expected for such transitions after phase space and isospin coupling corrections (here only 1.1%) are included (see Ref. 1). Indeed, Fig. 2 shows that the transitions to the pair of previously unobserved "mirror" levels at 11.13 ± 0.05 MeV in Li^7 and 10.79 ± 0.04 MeV in Be^7 are identical, considering the background subtraction and statistical errors. Therefore, these two states can be assigned a T = 3/2 isospin. Their excitation energies are close to the theoretical estimates for the lowest T = 3/2 state[5,6] in Li^7—the first three T = 3/2 states are predicted to be $3/2^-$(10.9[5], 10.1[6]); $1/2^-$(~ 12.4[5,6]), and $5/2^-$(13.7[5], 13.2[6] MeV).

We note that the angular distributions in Fig. 2 have the same shape as is standardly observed for known L = 0 transitions at 43.7 MeV (see Fig. 3 of Ref. 3). Due to angular momentum conservation, this also restricts our transitions to be to the $3/2^-$ states. These two T = 3/2 states are therefore the lowest ones—analogs of the He^7 and B^7 ground states.

The difference between the two excitation energies in Li^7 and Be^7, which is about 340 keV, is qualitatively in accord with the variation of the Coulomb energy with excitation, as calculated by Fairbairn;[7] with the difference in pairing energies between the T = 1/2 and T = 3/2 states, estimated by Wilkinson[8] for the 1p shell; and with a probable Thomas-Ehrman shift.

These two T = 3/2 levels are broad. Correcting for the experimental energy resolution, we find full widths at half maximum of 268 ± 30 keV for Li^{7*} and 298 ± 25 keV for Be^{7*}. These two widths are very similar and both states can decay through three T = 3/2 channels: He^6+p, Li^{6*}(T = 1) + n, He^4+p+2n for Li^{7*}; and Be^6+n, Li^{6*}(T = 1) + p, He^4+2p+n for Be^{7*}.

The mass of the He^7 nucleus can be obtained from the mass of Li^{7*}(T = 3/2), taking into account the neutron-hydrogen atom mass difference and calculating the Coulomb energy difference from the pair He^6 - Li^{6*}(T = 1). We find for He^7 a mass excess of 26.03 ± 0.15 MeV[9] in the C^{12} system; therefore, He^7 is definitely unbound to neutron emission by about 360 keV.[10] Assuming the first T = 3/2 level of Li^7 to be lower than 10.81 MeV, Balashov[6] found that He^7 would be a β-emitter with a half life of 30-100 msec. He^7 being unbound, the assignment of 50 μsec for its half life, which appears in the Chart of the Nuclides,[11] presumably quoted from Ref. 6 through a misprint in its abstract,[12] should be dropped.

A similar calculation to that for He^7, but using the T = 3/2 state in Be^7 and the Coulomb energy difference from the pair Be^{10} - B^{10*}(T = 1), indicates a mass excess of 27.99± 0.15 MeV[9] for B^7. Though this value is smaller than the one predicted by Goldanskii[13] (29.4 ± 0.5 MeV in C^{12} system), B^7 is still quite unstable for particle emission, decaying to Li^5+2p, Be^6+p and α+3p.

To estimate the mass of He^8, we can use the arguments reported by Goldanskii,[14] namely that the difference between the binding energies of the fourth and third neutrons of the $1p_{3/2}$ shell, $B_n(He^8) - B_n(He^7)$, is smaller than for the second and first neutrons, $B_n(He^6) - B_n(He^5)$, but larger than $B_n(Li^9) - B_n(Li^8)$ where the extra proton disturbs, by a deuteron-like bond, the pairing between the two neutrons. Using the mass of He^7 as calculated above, we obtain the following double inequality:

$$31.6 \text{ MeV} < \text{mass excess } (He^8) < 32.4 \text{ MeV} .$$

Since the lightest particle unstable channel is He^6 + 2n, the mass excess of which is 33.74 MeV, He^8 should be stable to neutron emission by at least 1.3 MeV.[15]

After theoretical predictions[14,16] and experimental hints,[17] the particle stability of He^8 has recently received its most reliable proof with the observation by Nefkens[18] of what is thought to be its β-decay. He^8 can decay to the 3.22 MeV (1+) and, if it is a 1+ level,[19] the 0.978 MeV level of Li^8. If the latter decay is possible, our He^8 mass predicts an end point energy lying between 9.7 and 10.5 MeV, which is slightly outside the values given by Nefkens, 13 ± 2 MeV. A lower energy than his would produce a lower value of log ft; his value of 4.3 seems somewhat high for this allowed transition.

These results for He^8 can be used to limit the mass excess of the tetraneutron n^4, which has recently "regained" stability with the apparent discovery that the trineutron n^3 is bound by about 1 MeV.[20] Our He^8 mass and the observed β-decay[18] require a mass excess of more than 29.2 MeV for n^4; if Goldanskii's treatment[14] is still meaningful for such very light nuclei, the pairing energy for the last two neutrons $[B_n(n^4)-B_n(n^3)]$ would be <u>at most</u> 1 MeV, which appears somewhat low.

To summarize, the determination of the lowest T = 3/2 level energies and widths in Li^7 and Be^7 implies that He^7 is unbound by about 360 keV with a very short half-life (some 10^{-21} sec.), that B^7 is even more unbound, but that He^8 is bound, decaying by β^--emission with a maximum energy of the order of 10.1 ± 0.4 MeV.

FOOTNOTES AND REFERENCES

[†] Work performed under the auspices of the U. S. Atomic Energy Commission.

[*] CNRS and NATO fellow, visitor from Laboratoire Joliot-Curie de Physique Nucleaire, Orsay, France.

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9. This error of 150 keV is considerably larger than the errors on the masses of the analog Li^{7*} and Be^{7*} states and is our estimate of the accuracy of a Coulomb energy correction in such light nuclei.
10. In a note added in proof in Ref. 4, a particle identifier spectrum was shown with a group marked He^7(P). This was in fact submitted as He^7(?). The possibility that the particular group could be He^7 was based on its lifetime given in Ref. 11, which is herein shown to be erroneous.
11. Chart of the Nuclides, Knolls Atomic Power Laboratory, USAEC, 7th ed.
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15. Calculations in the mass 8, T = 2 system based on this He^8 mass give for C^8 a mass excess of 36.4 ± 0.8 MeV, which agrees with the predictions of Ref. 13 (< 38 MeV in the C^{12} system), and implies that C^8 is unbound.

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FIGURE CAPTIONS

Fig. 1. Energy spectra for the $Be^9(p,t)Be^7$ and $Be^9(p,He^3)Li^7$ reactions at 32.5° in the laboratory system.

Fig. 2. Angular distributions for the $T = 3/2$ states at 10.79 MeV in Be^7 and 11.13 MeV in Li^7. The cross sections for the Li^7 state have been corrected for phase-space and isospin coupling by the factor of 0.989. The errors which appear on the figure are only statistical.

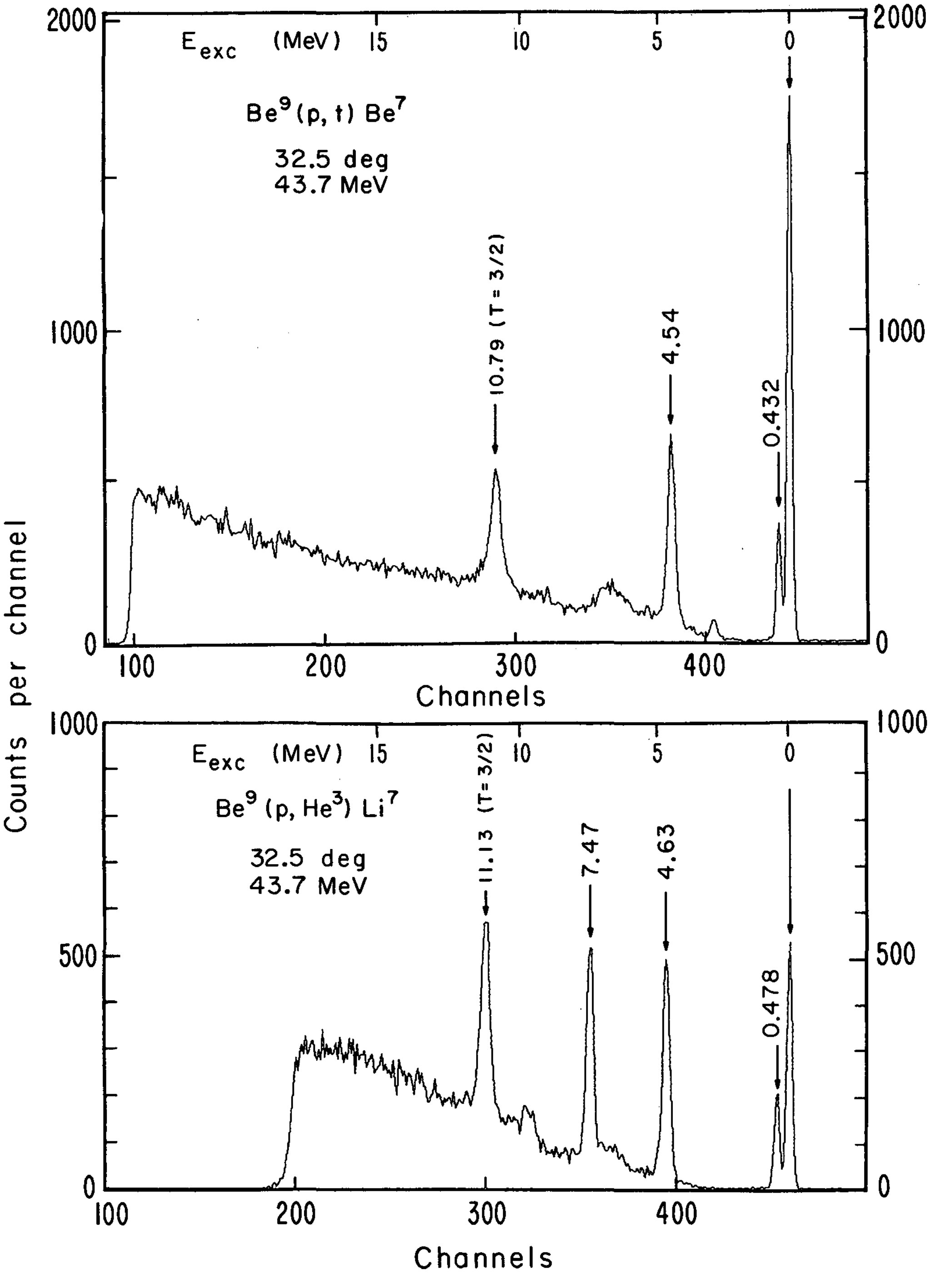

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Fig. 1

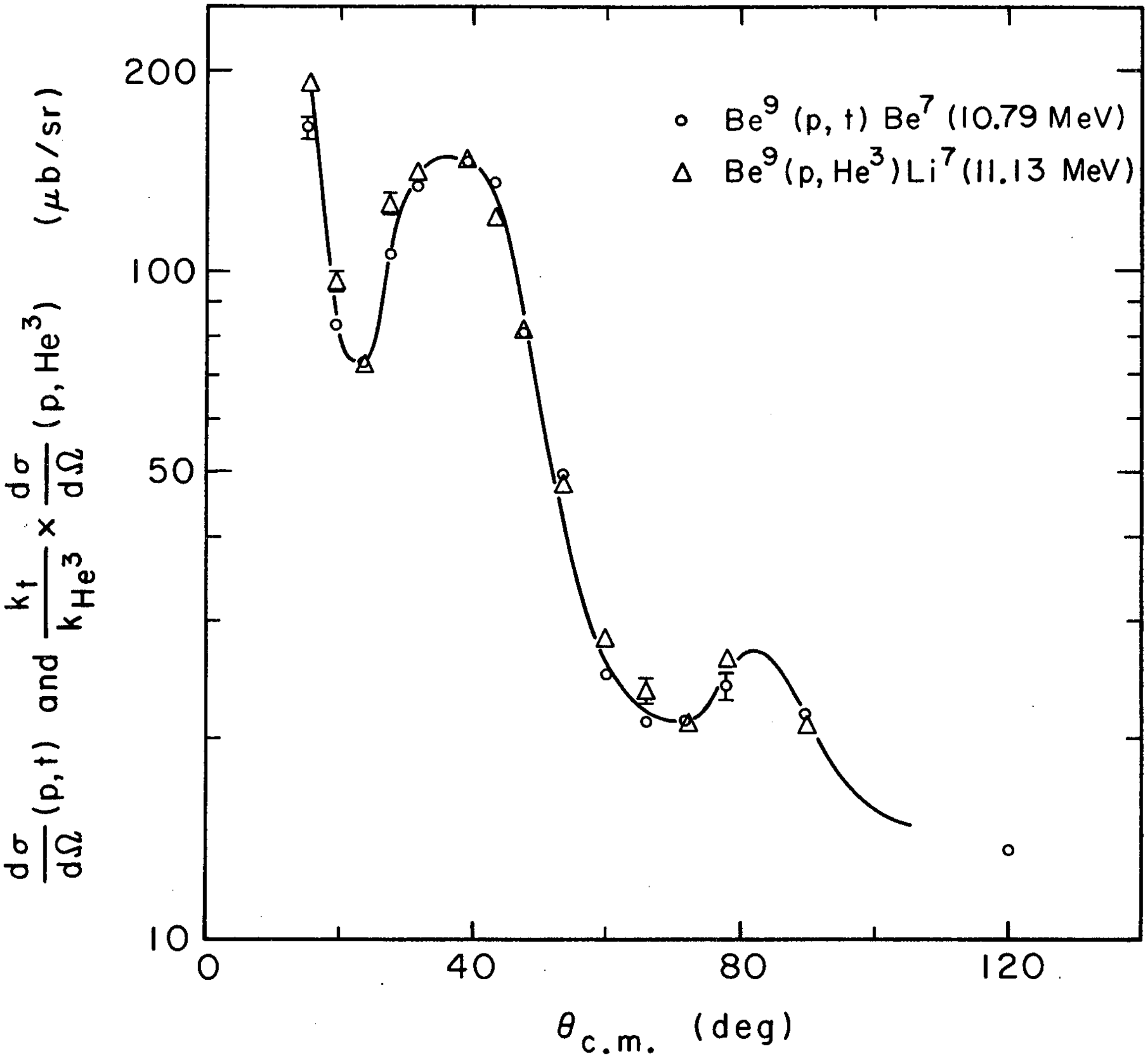

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Fig. 2