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Author
Wilcox, K.H.

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K. H. Wilcox, R. B. Weisenmiller, G. J. Wozniak,
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THE (^{9}Be,^{8}B) REACTION AND THE UNBOUND NUCLIDE ^{10}Li[†]

K. H. Wilcox, R. B. Weisenmiller, G. J. Wozniak,
N. A. Jelley[*], D. Ashery[‡], and Joseph Cerny

Lawrence Berkeley Laboratory
and Department of Chemistry
University of California
Berkeley, California 94720

August 1975

Counter-telescope and recoil-coincidence techniques were employed to study the ^{9}Be(^{9}Be,^{8}B)^{10}Li reaction at 121 MeV. A cross section of ∿ 30 nb/sr (c.m.) was observed, indicating a ^{10}Li mass-excess of 33.83 ± 0.25 MeV. This corresponds to ^{10}Li being unbound to ^{9}Li + n by 0.80 ± 0.25 MeV.

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Mass measurements of new highly neutron-excess nuclei provide important tests of the theoretical relations used to predict the limits of nuclear stability and the onset of new nuclear decay modes [1]. Experimental masses in the very light nuclei have proved particularly interesting since large discrepancies have been found between predicted and observed mass-excesses. Two such cases have been the unexpected observations of the particle stability of ^{11}Li [2] and ^{14}Be [3], which were predicted at the time of their discovery to be well unbound.

If one excludes many-neutron systems and hydrogen isotopes, all $T_z = 2$ nuclei in the light elements are nucleon stable and have known masses

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[*] Present Address: Nuclear Physics Laboratory, University of Oxford, England.

[‡] Permanent Address: Tel-Aviv University, Israel.

with the exception of ^{10}Li, which has been established to be particle unbound [2,3] but for which a mass-excess has not been determined [4]. Studies of ^{10}Li are difficult since it cannot be reached by standard techniques on stable targets. However, by employing the $|\Delta T_z| = 3/2$ rearrangement reaction, (^{9}Be,^{8}B), we have produced ^{10}Li via the ^{9}Be(^{9}Be,^{8}B)^{10}Li reaction.

A 121 MeV ^{9}Be^{+3} beam from the Lawrence Berkeley Laboratory 88-inch cyclotron was used to bombard a 0.68 mg/cm^2 ^{9}Be foil. Typical beam intensities of 80 nA (4+) on target were produced by a Penning ion gauge source. Beryllium vapor was supplied to the arc by support-gas-induced sputtering of a piece of Be metal located just outside of the arc. ^{8}B exit particles were identified by a detector telescope, subtending a solid angle of 0.3 msr, consisting of two transmission (ΔE) detectors, 53 and 45 μm thick, a 210-μm E detector, and a 500-μm reject detector. The method of data handling has been described previously [5] and involves in part a comparison of two particle identification signals to reduce background; this comparison eliminated ∿ 25% of the ^{9}Be-induced events.

Due to the low yield of the (^{9}Be,^{8}B) reaction, it was necessary to reduce the background from target contaminants and random pulse pileup by additionally requiring the ^{8}B particles to be in coincidence with an event in a recoil telescope. The recoil telescope subtended a solid angle of 15 msr and consisted of ΔE and E detectors of thickness 11 and 48 μm, respectively, backed by a 500-μm reject detector. Figure 1(a) shows schematically the location of the detectors in the scattering chamber. A large recoil solid angle is required because the recoiling ^{10}Li nucleus decays in flight to ^{9}Li + n, resulting in a ^{9}Li maximum breakup cone angle of about 10 degrees in the laboratory. The thickness of the ΔE detector was chosen to eliminate background from the ^{12}C(^{9}Be,^{8}B)^{13}B and ^{16}O(^{9}Be,^{8}B)^{17}N reactions, induced on target contaminants, by stopping the ^{13}B and ^{17}N recoil nuclei while permitting the ^{9}Li recoil daughters to pass through into the E detector. Fast timing techniques were used in establishing the coincidence between the ^{8}B and its associated recoil and to eliminate inter-beam-burst pileup. (A more detailed discussion of the experimental technique is given in ref. 6.)

Figure 1(b) presents a particle identification spectrum of some of the data taken with the ^{9}Be target. Those events for the entire experiment lying within a very broad ^{8}B window, which also had a recoil coincidence and an energy greater than 70 MeV, are shown cross-hatched. (The $^{9}Li + n$ threshold was equivalent to $E(^{8}B) = 75.8$ MeV.) It is seen that any ^{10}B events tailing into the ^{8}B region are totally eliminated by this requirement.

An energy calibration for the $(^{9}Be,^{8}B)$ reaction was obtained by observing at small angles the $^{40}Ca(^{6}Li,^{8}B)^{38}Ar$ reaction to the ground and first excited (2.17 MeV) states of ^{38}Ar, initiated by an 80.6 MeV $^{6}Li^{+2}$ beam. In addition the $^{28}Si(^{6}Li,^{8}B)^{26}Mg$ and $^{16}O(^{6}Li,^{8}B)^{14}C$ ground state reactions were used. These reactions [7] have reasonable cross sections (5-10 μb/sr) and populate discrete states yielding ^{8}B with energies between 62 and 71 MeV, close to the energy of ∿ 75 MeV expected from the $^{9}Be(^{9}Be,^{8}B)^{10}Li$ ground state reaction at 14°. Such a calibration procedure is convenient because 80.6 MeV $^{6}Li^{+2}$ and 121 MeV $^{9}Be^{+3}$ have essentially the same magnetic rigidity and charge-to-mass ratio, and therefore the same cyclotron magnetic field and beam transport magnet currents. To change beams only a calculable adjustment in the cyclotron frequency is needed; the energy of the beam was determined using a high-precision analyzing magnet.

The $^{12}C(^{9}Be,^{8}B)^{13}B$ reaction was also studied separately, both to obtain a calibration point at higher energies and to study the yield of the $(^{9}Be,^{8}B)$ reaction on a major target contaminant. A ^{8}B energy spectrum from this reaction at 14° is shown in fig. 2(a). The ground state population is too low (∿ 200 nb/sr) to be useful for calibration purposes. However, the sharp peak at 81 MeV provided a useful point; it corresponds to the region of excitation of a pair of doublets [8] between 3.48 and 3.71 MeV, so that its energy is only uncertain to ± 120 keV. This, together with the $(^{6}Li,^{8}B)$ data, established an accurate energy calibration.

A spectrum of all the ^{8}B data from reactions on the ^{9}Be target, representing 6950 μC of ^{9}Be beam (fully stripped), is shown in fig. 2(b). The same data, with the additional requirement that each count be in coincidence with an event in the recoil detector (located at 33° in the laboratory), are seen in fig. 2(c). With this requirement, elimination of ^{8}B nuclei arising from reactions on major target contaminants was essentially complete. Further, although isotope resolution in the recoil particle identification spectra was poor, it was adequate to show that all the associated recoils from the events in fig. 2(c) appear in the region expected for ^{9}Li nuclei.

Two independent investigations were made of the $^{9}Be(^{9}Be,^{8}B)^{10}Li$ reaction using these techniques. Good agreement between the two was seen and all data presented here are a summation of both determinations. We have assumed of necessity that the observed peak arises predominantly from the population of ^{10}Li in its ground state. (Based on simple particle-particle, hole-hole theorems, the two lowest states of ^{10}Li could be very similar to those of ^{12}B, in which they are separated by 0.95 MeV.) The width of this peak, approximately 1.2 ± 0.3 MeV FWHM, (c.m.), is of the correct order of magnitude for a single unbound state on the basis of neutron-tunneling calculations. At this angle of 14° the cross section for population of the ground state of ^{10}Li was ∿ 30 nb/sr (c.m.). The observed Q value for the ^{9}Be(^{9}Be,^{8}B)^{10}Li ground state reaction was -34.06 ± 0.25 MeV, corresponding to a mass-excess for ^{10}Li of 33.83 ± 0.25 MeV.

The nucleus ^{10}Li is thus unbound to ^{9}Li plus a neutron by 0.80±0.25 MeV (using the recent remeasurement [9] of the ^{9}Li mass), somewhat more unbound than the current prediction [10] of 0.21 MeV based on the Garvey-Kelson method. It is also substantially more unbound than is indicated by the results of Abramovich et al.[11], who observed an anomaly in the ^{7}Li(t,p)^{9}Li excitation function corresponding to an excitation energy of 21.185 MeV in ^{10}Be. On the basis of its small partial width, they assigned it as the T = 2 analogue of the ^{10}Li ground state, thereby deducing that ^{10}Li should be unbound by 0.062 ± 0.060 MeV.

An attempt was also made with the (^{9}Be,^{8}B) reaction to determine the mass-excess of the $T_z = 5/2$ nuclide ^{15}B by reactions on a ^{14}C target. A 121 MeV ^{9}Be beam was again used, bombarding a 100 μg/cm^{2} carbon target enriched to ∿ 80% in ^{14}C. The experimental technique was similar to that described for the ^{9}Be(^{9}Be,^{8}B)^{10}Li reaction, except that a single recoil counter of about 20 μm thickness, backed by a reject detector, was used. ^{8}B particles from the relatively high-yield ^{12}C(^{9}Be,^{8}B)^{13}B reaction were not sufficiently eliminated by the recoil angle requirement to permit positive identification of any peaks due to the formation of ^{15}B. An upper limit of 50 nb/sr (c.m.) can be set for the ^{14}C(^{9}Be,^{8}B)^{15}B ground state reaction at 14° in the laboratory. (Also see ref. 6).

These results on ^{10}Li add another $|\Delta T_z| = 3/2$ nuclear rearrangement reaction to such reactions as (^{7}Li,^{8}B) [5] and (^{11}B,^{8}B) [12] as demonstrated tools to employ (albeit not always successfully) in studying the spectroscopy of new highly neutron-excess light nuclei.

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REFERENCES

1. J. Cerny, Proc. Int. Conf. Reactions between Complex Nuclei, Nashville, 1974, ed. R. L. Robinson, F. K. McGowan, J. B. Ball, and J. H. Hamilton, (North-Holland, Amsterdam/American Elsevier, N. Y., 1974) Vol. 2, p. 483.
2. A. M. Poskanzer, S. W. Cosper, E. K. Hyde, and J. Cerny, Phys. Rev. Letters 17, 1271 (1966).
3. J. D. Bowman, A. M. Poskanzer, R. G. Korteling, and G. W. Butler, Phys. Rev. C9, 836 (1974).
4. A preliminary value for the mass-excess of ^{10}Li determined by us using a less stringent technique was reported in reference 1. The present data should be considered as superseding that earlier result.
5. K. H. Wilcox, N. A. Jelley, G. J. Wozniak, R. B. Weisenmiller, H. L. Harney, and J. Cerny, Phys. Rev. Letters 30, 866 (1973).
6. K. H. Wilcox, Lawrence Berkeley Laboratory Report No. LBL-4029 (Ph.D. thesis), 1975 (unpublished).
7. R. B. Weisenmiller, K. H. Wilcox, N. A. Jelley, G. J. Wozniak, and J. Cerny, to be published.
8. F. Ajzenberg-Selove, Nucl. Phys. A152, 1 (1970).
9. E. Kashy, W. Benenson, D. Mueller, R. G. H. Robertson, and D. R. Goosman, Phys. Rev. C11, 1959 (1975).
10. N. A. Jelley, J. Cerny, D. P. Stahel, and K. H. Wilcox, Phys. Rev. C11, 2049 (1975).
11. S. N. Abramovich, B. Ya. Guzhovskii, A. G. Zvenigorodskii, and S. V. Trusillo, Izv. Akad. Nauk SSSR. Ser. Fiz. 37, #9, 1967 (1973): transl. Bull. Acad. Sci. U.S.S.R., Physical Series, 37,#9,144 (1973).
12. D. K. Scott, B. G. Harvey, D. L. Hendrie, L. Kraus, C. F. Maguire, J. Mahoney, Y. Terrien, and K. Yagi, Phys. Rev. Letters 33, 1343 (1974).

FIGURE CAPTIONS

Fig. 1. (a) Schematic drawing of the scattering chamber setup showing orientation of the detectors and target; the solid angles of the ^{8}B and recoil telescopes were 0.3 and 15 msr, respectively. (b) Particle identification spectrum resulting from the bombardment of ^{9}Be by 121 MeV ^{9}Be. The location of high energy events in the ^{8}B region having a recoil coincidence is shown cross hatched. See text.

Fig. 2. Several energy spectra resulting from the bombardment of ^{12}C and ^{9}Be targets by a 121 MeV ^{9}Be beam and observed at 14° in the laboratory: (a) The ^{12}C(^{9}Be,^{8}B)^{13}B reaction. (b) The ^{9}Be(^{9}Be,^{8}B)^{10}Li reaction singles events. (c) A two channel sum of the ^{9}Be(^{9}Be,^{8}B)^{10}Li reaction coincidence events.

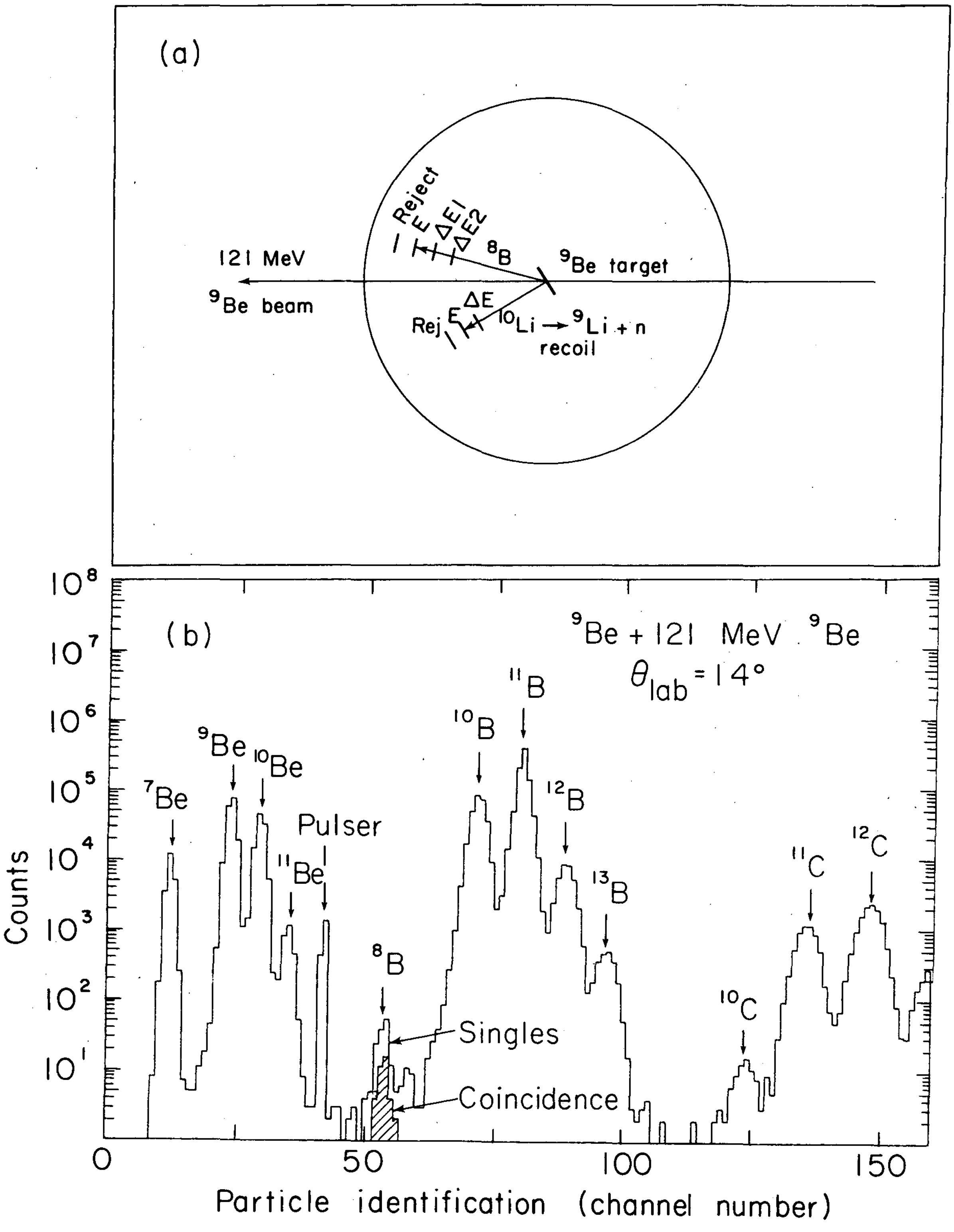

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Fig. 1

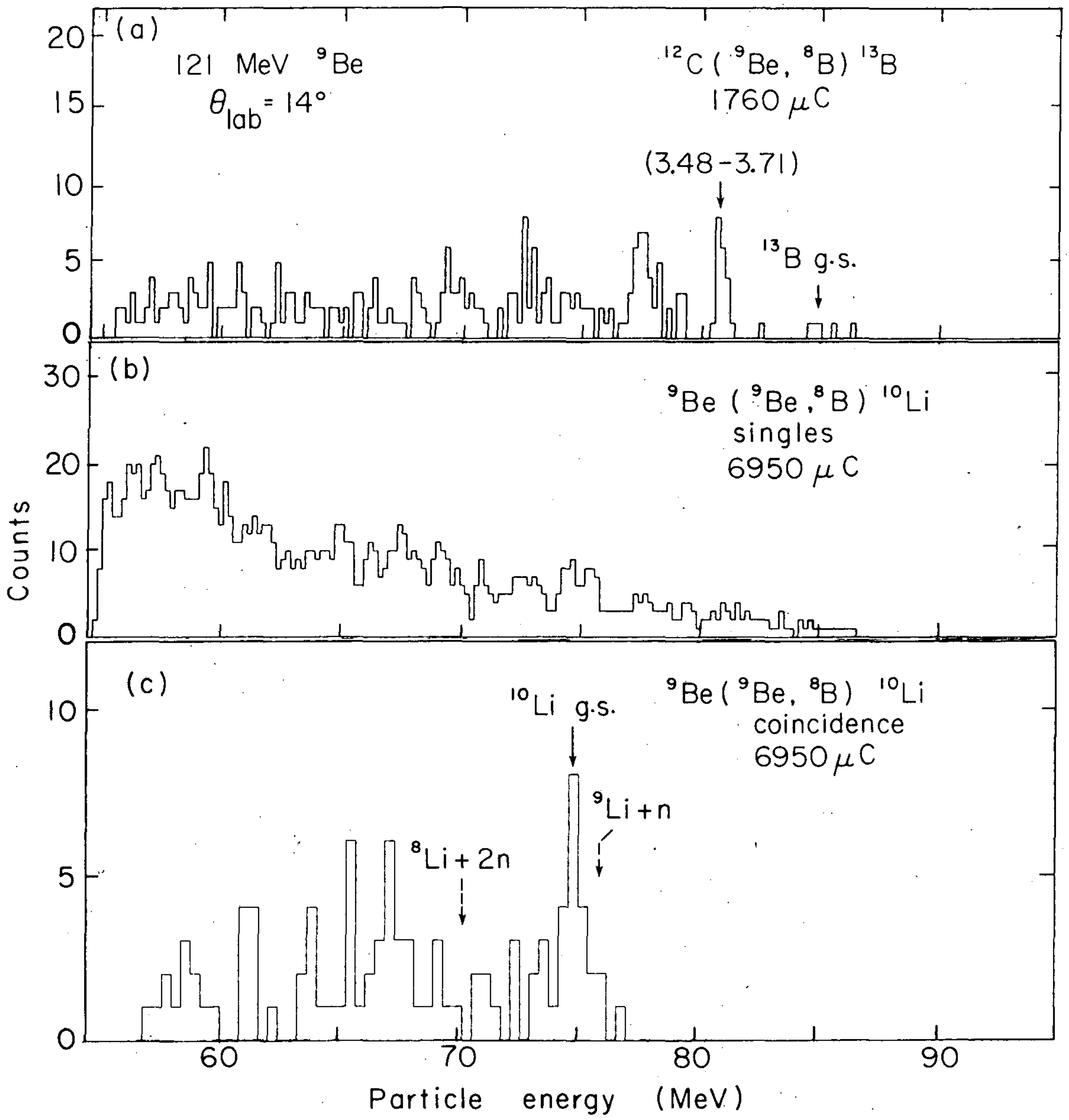

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Fig. 2

TECHNICAL INFORMATION DIVISION
LAWRENCE BERKELEY LABORATORY
UNIVERSITY OF CALIFORNIA
BERKELEY, CALIFORNIA 94720