NEW ISOTOPES: ^{11}Li, ^{14}B, AND ^{15}B†

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Data obtained with semiconductor detectors and a particle-identifier system on fragments ejected from uranium bombarded with 5.3-GeV protons show that ^{11}Li, ^{14}B, and ^{15}B are particle stable, ^{10}Li is particle unstable, and ^{13}Be is most probably particle unstable.

The feasibility of using semiconductor detectors in conjunction with a power-law–type particle identifier[1,2] as a tool for the study of light fragments produced in reactions of gigaelectron-volt protons with heavy target nuclei has been successfully demonstrated. All the known particle-stable isotopes with $Z \leqslant 6$ (with the exception of ^{9}C and ^{16}C) were readily observed. As a preliminary experiment, prior to conducting the study outlined above, a search for new particle-stable isotopes with $Z \leqslant 5$ was undertaken. The initial measurements centered on the possibly bound nuclei ^{14}B[3] and ^{15}B,[3,4] since no unknown isotopes of $Z \leqslant 4$ were expected.[3,4] As a result of these investigations, we wish to report the identification of three new isotopes: ^{11}Li, ^{14}B, and ^{15}B.

This experiment was performed in the Bevatron's 5.3-GeV external proton beam which impinged on a 26-mg/cm^2 uranium foil mounted in the center of an evacuated 36-in. diam scattering chamber. Beam pulses 0.8 sec long and containing an average of 5×10^{11} protons occurred every six seconds. A counter telescope consisting of two ΔE detectors (82 and 61 μ thick), an E detector (300 μ), and a rejection detector (100 μ) was placed at an angle of 40°. All the counters were phosphorus-diffused silicon transmission detectors. A magnet and an 8.5-mg/cm^2 aluminum foil were placed in front of the telescope, and all detectors except the rejection detector were separately collimated. (See also Ref. 5.)

The signals from these detectors fed a power-law–type particle-identifier system which has been completely described elsewhere.[1,2,5,6] Basically, two identifications of each particle traversing the counter telescope were made, and stringent requirements were set on their agreement in order to improve the resolution of the identifier spectra and aid the search for small peaks in the presence of much larger ones. Consequently only 50% of the events were accepted. Fast coincidence and pile-up rejection techniques were employed to reduce background (see Refs. 1 and 6). Total energy and particle-identifier signals were stored in a two-parameter, 4096-channel pulse-height analyzer and the particle-identifier signal was also stored simultaneously in a 400-channel pulse-height analyzer.

Figure 1 presents two particle-identifier spectra, covering isotopes of Li, Be, B, and C, obtained under identical conditions except that the data for the lower curve were taken at one-half the counting rate of those for the upper curve. The predicted locations of the observed ^{14}B and ^{15}B peaks are indicated on the figure by arrows as are the expected positions of the neighboring isotopes ^{9}C and ^{10}C. An additional peak at the predicted location for ^{11}Li was also observed.[7] A third experiment under somewhat different conditions yielded results exactly comparable with those in the lower curve.

It is necessary to eliminate the possibility that these small peaks corresponding to ^{11}Li, ^{14}B, and ^{15}B were caused by pile-up effects (see Refs. 5 and 6) arising from the high counting rates encountered in these experiments. This was accomplished in two ways. First, observation of chance coincidence spectra arising from pulser-simulated particles in coincidence with real events showed no indication of peaks in the positions of these proposed new isotopes. Second, since effects due to pile-up should be proportional to counting rate, the two sets of data presented in Fig. 1 were taken. If any of these new peaks arose from pile-up phenomena, that peak should be a factor of 2 smaller in the lower curve. All peak heights are the same in both curves, although the reduction of pile-up can be observed in the deeper valleys

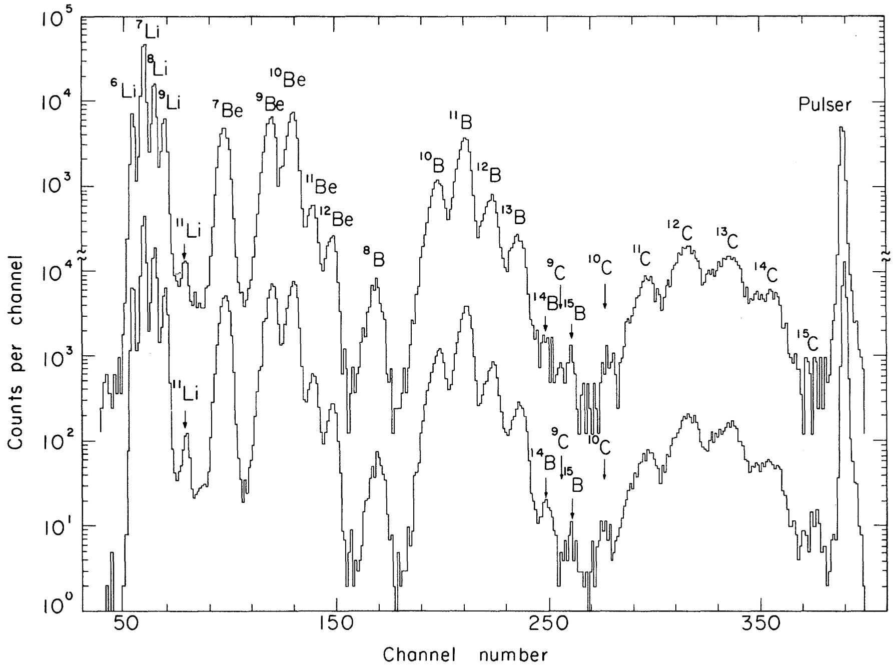

FIG. 1. Particle-identifier spectra resulting from the bombardment of uranium by 5.3-GeV protons. An energy loss from the E detector between 20 and 60 MeV was accepted. The solid angle subtended by the detectors was 0.8 $\times 10^{-4}$ sr for the lower curve and 1.7×10^{-4} sr for the upper curve with data-collection times of 66 and 30 h, respectively. The two spectra were normalized by slightly shifting the upper curve.

around the smaller peaks of the lower curve.[8]

Figure 2 presents two-parameter data from an additional experiment centered on the ^{11}Li region. The contour plot and its projection again show a peak for ^{11}Li, and the fact that the ^{11}Li events appear in the expected energy range supports the assignment. The two-parameter data for the ^{14}B and ^{15}B isotopes also appeared in their appropriate energy intervals. Furthermore, the areas of the ^{11}Li, ^{14}B, and ^{15}B peaks seem reasonable, especially when one notes that the ratios of the ^{14}B and ^{15}B peaks relative to ^{13}B are quite similar to those of ^{11}Be and ^{12}Be relative to ^{10}Be. These peak areas do not accurately represent relative yields because of the narrow and different ranges of total energy accepted for each particle.[9]

Isotopes not observed.—The particle instability of ^{10}Li is clearly shown by the absence of a peak in the expected position, especially since ^{11}Li is observed. If ^{13}Be were particle stable, we would have expected a much larger yield at its predicted position; this indicates that ^{13}Be is probably unbound. Investigations of the helium isotopes showed the presence of ^{3}He, ^{4}He, ^{6}He, and ^{8}He nuclei.[10] The possible isotope ^{10}He was not observed and an upper limit for its intensity of 1/100 the ^{8}He peak can be set; however, this limit is not so low as that previously established from ^{252}Cf-fission data.[5] The instability of ^{10}He, ^{10}Li, and ^{13}Be is in accordance with prediction.[3,4]

Observed isotopes.—Since ^{15}B was predicted to be bound[3,4] and ^{14}B was expected to be marginally bound,[3] the present observations of their existence were not unexpected. On the other hand, the generally reliable calculations of Garvey and Kelson[3] predicted ^{11}Li to be unbound by 2.5 MeV. Our observation of this isotope was, therefore, very surprising. However, only for this isotope and[6] for ^{8}He have their binding energies been significantly outside their expected errors.

For lack of a successful theory in this mass region, we may examine the systematics of two-neutron binding energies as a function of charge for a given neutron number.[11] The curve for $N=6$ has a kink in it reflecting the fact that ^{9}Li and ^{8}He are appreciably better bound than one would expect by extrapolation from masses nearer stability. Thus a similar kink in the $N=8$ curve would be reasonable and would be consistent with the particle stability of ^{11}Li. A continued extrapolation, however, would still be consistent with the instability of ^{10}He.

These three new isotopes should have beta-

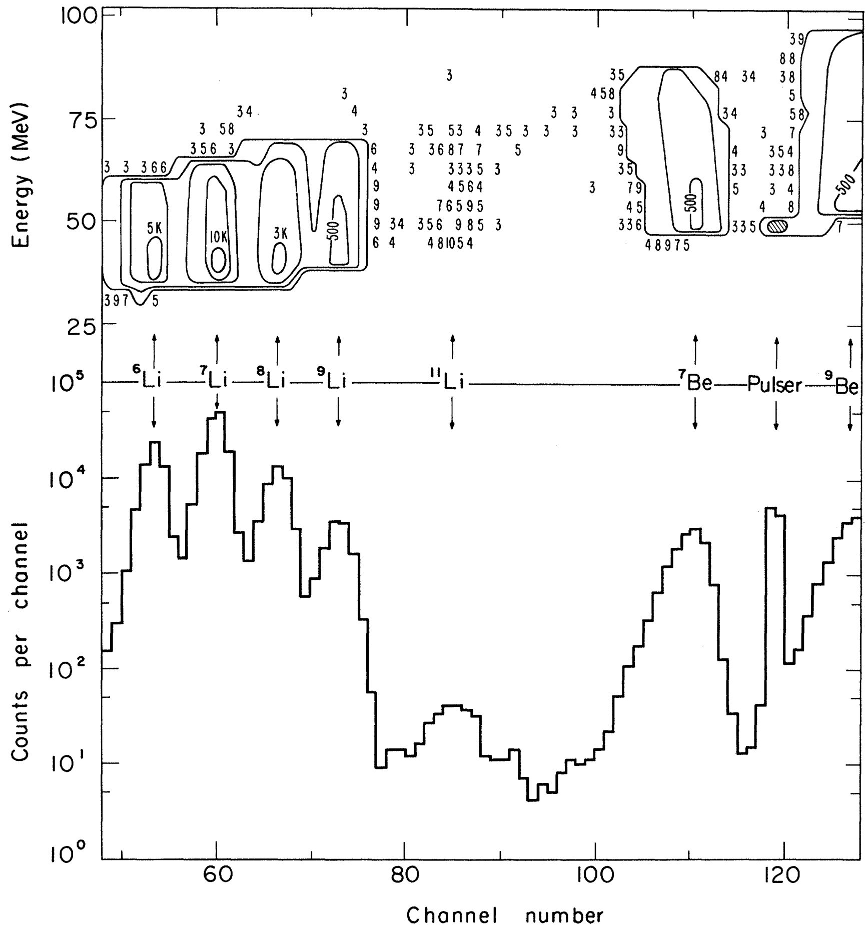

FIG. 2. The upper portion of the figure is a contour plot of counts as a function of total energy and particle-identifier signal centered in the ^{11}Li region. Unless labeled, the contour lines indicate the 10, 100, 500, and 5000 count levels. Counts less than 10 are indicated, except for 1's and 2's, which have been suppressed for clarity. The cross-hatched peak is due to a pulser which was run at a slow rate throughout the experiment as a stability check. The energy loss accepted from the E detector was 10 to 87 MeV. No correction has been made for energy loss in the target or in the 8.5-mg/cm^2 Al foil. The lower portion of the figure shows the projection of these data onto the particle-identifier axis. The solid angle subtended by the detectors was 0.8×10^{-4} sr, and the data were collected for 41 h.

decay Q values of about 20 MeV and should all be delayed neutron emitters—^{15}B in almost 100% of its decays. In fact, the assignment[12] of an (11.4 ± 0.5)-msec delayed neutron activity to ^{12}Be on the assumption that ^{11}Li was particle unstable must be re-examined. The logft values for the beta decay of ^{11}Li have been calculated for us by Kurath[13] and are consistent with an 11.4-msec half-life if ^{11}Li is bound by 3.5 ± 2 MeV, which appears somewhat large. As was reported earlier,[12] this half-life is consistent with the logft values calculated for ^{12}Be if its Q_β is 11.7 ± 1 MeV. This Q_β is in very good agreement with the Q_β of 11.5 ± 0.2 MeV calculated from a ^{12}Be mass based[14] on the $T=2$ states of ^{12}C and ^{12}B. Thus the 11.4-msec half-life is slightly more consistent with estimates of the decay properties of ^{12}Be than with ^{11}Li but is certainly open to question at present. The assignment cannot be clarified on the basis of cross-section systematics.[15] In any event, the particle stability of both ^{11}Li and ^{12}Be is established by the present data.

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[4]A. E. Baz', V. I. Gol'danskii, and Ya. B. Zel'dovich, Usp. Fiz. Nauk 72, 211 (1960) [translation: Soviet Phys.–Usp. 3, 729 (1961)].

[5]S. W. Cosper, J. Cerny, and R. C. Gatti, Phys. Rev. (to be published).

[6]J. Cerny, S. W. Cosper, G. W. Butler, R. H. Pehl, F. S. Goulding, D. A. Landis, and C. Dètraz, Phys. Rev. Letters 16, 469 (1966).

[7]This peak falls exactly half-way between the positions that would be occupied by the unbound nuclei ^{6}Be and ^{5}Be.

[8]It was also considered that a peak could arise from the disintegration of a nucleus in the Al foil or the front surface of the first ΔE detector [see R. W. Ollerhead, C. Chasman, and D. A. Bromley, Phys. Rev. 134, B74 (1964)]. However, calculation shows that this process is orders of magnitude too small to account for the observed peaks. The peaks could not be due to hyperfragments because their expected short lifetimes would make the yields at the two distances from the target very different.

[9]The energies observed in these experiments are considerably above the Coulomb barriers for the emission of these fragments from uranium and, therefore, are in a region where fragment intensity is decreasing with increasing energy.

[10]No peaks were observed in the positions expected for ^{7}He and ^{9}He in agreement with previous results (see Ref. 5).

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[15]I. Dostrovsky, R. Davis, A. M. Poskanzer, and P. L. Reeder, Phys. Rev. 139, B1513 (1965); A. M. Poskanzer, R. A. Esterlund, and R. McPherson, Phys. Rev. Letters 15, 1030 (1965).

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π-p CHARGE-EXCHANGE PROCESSES IN THE REGION OF 2 GeV/c. A. S. Carroll, I. F. Corbett, C. J. S. Damerell, N. Middlemas, D. Newton, A. B. Clegg, and W. S. C. Williams [Phys. Rev. Letters 16, 288 (1966)].

An error was made in calculating the sign of the interference term between the Regge amplitude and the resonant amplitudes. As a result the full curves in Fig. 1 correspond to a $J=l+\frac{1}{2}$ assignment to the $N^*(2190)$ and the broken curves to a $J=l-\frac{1}{2}$ assignment. Our conclusions should therefore be changed to say that the analysis favors a $J=l+\frac{1}{2}$ assignment.

This error was drawn to our attention by Dr. R. J. N. Phillips; we are indebted to him for this. Dr. Phillips has also indicated that the tails of other resonances than those included in our calculation can make important changes in the calculated curves, and that the distinction between $J=l+\frac{1}{2}$ and $l-\frac{1}{2}$ may not be so clear cut. The dominance of the Regge amplitude at this low energy is still supported.

COHERENT SCATTERING OF HOT ELECTRONS IN GOLD FILMS. J. G. Simmons, R. R. Verderber, J. Lytollis, and R. Lomax [Phys. Rev. Letters 17, 675 (1966)].

Equation (1) is correct only for electrons escaping from the upper surface of the gold electrode, for which case the component of momentum in the plane of the films is conserved as the electron crosses the electrode-vacuum interface. In the case of electrons escaping from a pinhole edge, the component of momentum parallel to the edge is conserved but the component normal to the edge is not. Under these conditions the image at the phosphor screen is semicircular, and the radius is given by

$$r=2s\left[\frac{(V_b+\eta)\sin^2 2\theta-(\varphi+\eta)}{V_a}\right]^{1/2}.$$

In the third sentence in the fourth paragraph substitute 180° for 90°. The inequality $|v_{\parallel}|\sin\beta>[(\varphi+\eta)2/m]^{1/2}$ should read $|v_{\parallel}|\cos\beta>[(\varphi+\eta)2/m]^{1/2}$.