THE

PHYSICAL REVIEW

A journal of experimental and theoretical physics established by E. L. Nichols in 1893

SECOND SERIES, Vol. 133, No. 1B 13 JANUARY 1964

Another Search for H^5†

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(Received 23 August 1963)

An attempt has been made to produce the 110-msec energetic electron activity recently reported to result from photon irradiation of lithium. The activity has not been found in the high-energy proton bombardment of lithium, and the production cross section is $<5\times10^{-4}$ times that for producing Li^9 from boron under the same conditions. This indicates that the high-energy proton activation cross section of lithium for such an activity is ≤ 1 μb.

I. INTRODUCTION

THE production of a (110±30) msec electron activity with $E_\beta(\max)>15$ MeV, following the irradiation of lithium with 320-MeV bremsstrahlung, has recently been reported by Nefkens.[1] The production cross section was (1.8±0.6) μb. Nefkens suggested that the activity was H^5, produced in the reaction Li^7 $(\gamma,2p)$. It is expected[2] that, if H^5 were stable against particle emission, it would decay by emission of electrons with ≈20-MeV end-point energy to neutron-unstable states of He^5. Cence and Waddell have also searched for H^5 activity.[3] They attempted to produce the activity with the same reaction used by Nefkens. They irradiated Li^7 with 340-MeV bremsstrahlung and looked for neutrons following H^5 decay. From their published decay curves, the upper limit on the cross section for a 100-msec activity is about 0.1 μb, a limit a factor of ≈20 lower than Nefkens' result.[4]

We have attempted to produce the activity reported by Nefkens by irradiating lithium with high-energy protons. It is expected that with high-energy protons all spallation products would be produced with cross sections of the order of magnitude of a millibarn. If the activity were H^5, it would be produced in the reaction $Li^7(p,3p)H^5$, and also in pion-emitting reactions. We have compared the beta-ray activity produced in the irradiation of lithium with that produced in the irradiation of boron. The most prominent feature of the latter is the decay of 170-msec Li^9, produced in the reaction $B^{11}(p,3p)Li^9$. Nefkens has also measured the cross section for production of Li^9 in the bremsstrahlung irradiation of boron;[5] he found $\sigma_B(\gamma,2p)\approx 36$ μb.

II. EXPERIMENTAL PROCEDURE

A target consisting of a 1-in. cube of lithium metal was suspended by a lithium wire in a helium bag and irradiated with the 2-GeV external proton beam at the Brookhaven Cosmotron. Beam bursts were about 1 msec long and had a repetition time of 3.5 sec. To test the procedure, Li^9 was produced by the same $(p,3p)$ reaction on a boron target, consisting of boron powder in a negligibly thin polyethylene bottle.

The electron detector was a telescope consisting of a $\frac{1}{2}$-in. thick by 4-in. diam plastic scintillator separated by 1 in. from another plastic scintillator 4 in. thick by 5 in. in diameter. The front (thin) counter was at 90° from the beam direction and about $7\frac{1}{2}$ in. from the target. Both photomultipliers were turned off during the beam burst by grounding their second dynodes. Coincidences $(2\tau\sim10^{-7}$ sec) were required between pulses of more than ≈4 MeV from the large counter and pulses in the "through peak" of the thin counter. The coincidence signals went to a 200-channel analyzer used in the multiscaler mode, with a dwell time of 10 msec per channel. The multiscaler was triggered at each beam burst. The coincidence pulses were also used to gate a second analyzer in which 50-channel pulse-height spectra for the large counter were recorded during eight different time periods after each beam burst.

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† Under the auspices of the U. S. Atomic Energy Commission.

[1] B. M. K. Nefkens, Phys. Rev. Letters **10**, 55 (1963).

[2] C. H. Blanchard and R. G. Winter, Phys. Rev. **107**, 774 (1957); V. I. Gol'danskii, Zh. Eksperim. i Teor. Fiz. **38**, 1637 (1960) [translation: Soviet Phys.—JETP **11**, 1179 (1960)]; and references cited there.

[3] R. J. Cence and C. N. Waddell, Phys. Rev. **128**, 1788 (1962).

[4] This conclusion has been confirmed in a private communication from R. J. Cence (July 1963).

[5] B. M. K. Nefkens, Phys. Rev. Letters **10**, 243 (1963).

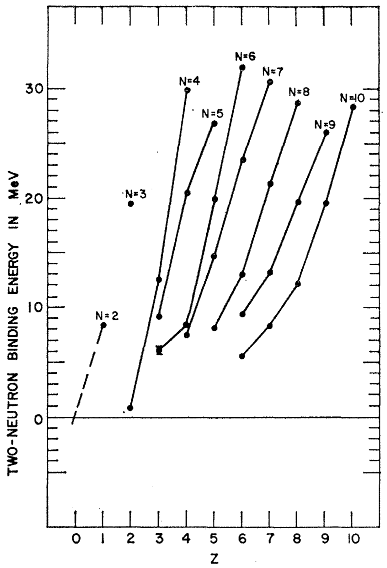

FIG. 1. Two-neutron binding energies, $-[M(Z,N)-M(Z,N-2)-2M_{\mathrm{neutron}}]\times c^2$, are plotted for light nuclei. The data are derived from the "1961 Nuclidic Mass Table" [L. A. König, J. H. E. Mattauch, and A. H. Wapstra, Nucl. Phys. **31**, 18 (1962)] with the addition of the Li^9 beta-decay energy, 13.5 ± 0.3 MeV [D. E. Alburger, Phys. Rev. **132**, 328 (1963)]. The line for $N=2$ is drawn as an illustration; the binding energy of the dineutron is assumed to be about zero.

III. RESULTS AND DISCUSSION

With no target in place, activities with half-lives of 10–20 msec and ≈ 800 msec were observed. With the boron target, electrons with the half-life of Li^9 were prominent. In the electron spectra from the lithium target, the few counts which were observed in the region corresponding to electron energies greater than 15 MeV decayed with a half-life of less than 30 msec.

A limit could be set on the amount of ≈ 110-msec activity, with ≈ 20-MeV beta end point, from the lithium target, relative to the amount of Li^9 from the boron target. This result leads to

$$\frac{\sigma(\mathrm{Li}^7+p\rightarrow \text{``}\mathrm{H}^5\text{''})}{\sigma(\mathrm{B}^{11}+p\rightarrow \mathrm{Li}^9)}\leq 5\times10^{-4}$$

for 2-GeV protons. The above ratio may be compared to the corresponding ratio of 5×10^{-2} found by Nefkens[1,5] for the production of these same "activities" by irradiation of the same targets with high-energy photons.

The cross section for the production of Li^9 from B^{11} has recently been measured to be 1.4 mb at 3 GeV.[6] Since such cross sections are nearly independent of bombarding energy in this region, the upper limit on the cross section for production of the searched-for "H^5" activity becomes about one microbarn.

To see if the different sizes of the Li^7 and B^{11} target nuclei would affect the probability of the $(p,3p)$ reactions, Monte Carlo calculations of the intranuclear cascade were performed.[7] The model was the same as that used by Metropolis *et al.*,[8] that is, a classical calculation using the impulse approximation. A difference was the use of a trapezoidal nuclear density distribution. The calculation was performed for incident protons of 400-MeV energy, the highest energy programmed at the present time. Those events were selected which led to the desired $(p,3p)$ cascade products and in which all the struck nucleons had escaped from the nucleus. The number of these events corresponded to cross sections of a few millibarns, with only twice as many resulting from the boron target as from the lithium target. In addition, there were ≈ 1.5 times as many events which led to $(p,2p)$ cascade products with various amounts of excitation energy. These could also lead to the desired final products by proton evaporation, but it is not believed that this would alter the calculated ratio of H^5 to Li^9 production drastically.

It is difficult to understand why the 110-msec activity reported by Nefkens, if it were actually H^5 or another spallation product of lithium, should have such a low cross section for production with high-energy protons.

There have been many theoretical discussions of the particle stability of H^5.[2] Since the most stable configuration into which H^5 can break up is H^3 plus two neutrons, stability against this decay mode is the crucial point. This point is discussed, e.g., by Blanchard and Winter,[2] who conclude that H^5 might be stable by a few hundred keV. Their conclusion is based on their estimate of the position of the analog state in He^5. $T(d,n)$ scattering results show a hint of a level in He^5 at about 19.6 MeV.[9] If this is evidence of the analog level, then, following the estimates of Blanchard and Winter for the Coulomb energy, H^5 would be unstable against tritium-two-neutron breakup by a few hundred keV. Due to the uncertainties in the nature and position of the analog state and in the magnitude of the Coulomb correction, these arguments seem rather inconclusive.

Because of the uncertainties in the theoretical estimates of the stability of H^5, it may be valuable to look directly at the systematics of two-neutron binding energies in light nuclei. These are presented in Fig. 1. The curves are much more regular than single-neutron-binding energies; this might be expected, since the odd-even effects are removed. It is clear that a serious departure from this regularity would be necessary if H^5 were to be stable against two-neutron emission.

ACKNOWLEDGMENTS

We wish to thank G. Friedlander, R. Davis, and L. Remsberg for helpful discussions, and T. Russell for assistance in the experiments.

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[6] I. Dostrovsky, R. Davis, A. M. Poskanzer, and P. Reeder (private communication, 1963).

[7] We are indebted to K. Chen, Z. Fraenkel, G. Friedlander, J. R. Grover, J. M. Miller, and Y. Shimamoto for the calculations.

[8] N. Metropolis, R. Bivins, M. Storm, A. Turkevich, J. M. Miller, and G. Friedlander, Phys. Rev. **110**, 185 (1958).

[9] J. E. Brolley, Jr., T. M. Putnam, L. Rosen, and L. Stewart, Phys. Rev. **117**, 1307 (1960).