be established.[24,25] This relationship, which is the beta-decay analog to the SIEGERT theorem[26,27] in electrodynamics, can be expressed as

$$\int i\alpha = \left(W_0 - \Delta M + \frac{7}{6}\frac{\alpha Z}{R}\right)\int \mathbf{r},$$

where ΔM is the neutron-proton mass difference in units mc^2 and $\alpha Z/R = 2\xi$. On the basis of this expression the predicted value of the matrix element ratio is

$$\int i\alpha \Big/ \int \mathbf{r} = +29.$$

The experimental value

$$\int i\alpha \Big/ \int \mathbf{r} = +32_{-17}^{+60}$$

agrees very well with this prediction of the conserved vector current hypothesis.

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Search for H^5

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Following the suggestion that H^5 might be stable against nucleon emission, a search was made for delayed neutrons resulting from the reaction $Li^7(\gamma,2p)H^5$. The targets were bombarded with a 340-MeV bremsstrahlung beam and the delayed neutrons detected in a shielded paraffin-moderated array of BF_3 counters. Counts were scaled in 14 delay channels of variable width and variable initial delay. Separated isotopes of Li^7 and Li^6 were used as targets. As H^5 cannot be produced from the bombardment of Li^6, counts observed during the bombardment of Li^6 were used to measure the background. After background subtraction, the data fall uniformly about zero and show no apparent lifetime. Assuming a 10-msec half-life, an upper limit for the activation cross section is $\sigma_A \leq 3\times10^{-32}$ cm^2. A comparison of this with the yield expected from the extrapolation of the measured yields of the reactions $B^{11}(\gamma,2p)Li^9$ and $F^{19}(\gamma,2p)N^{17}$ indicates that the upper limit for the activation cross section is of the order of 1% of the expected yield. Hence it appears unlikely that H^5 is stable against particle emission.

INTRODUCTION

IN this paper we present the results of an experiment previously reported,[1] and confirm the results of an independent experiment reported by Tautfest.[2] Following the suggestion by Blanchard and Winter that H^5 might be stable against nucleon emission,[3] we attempted to produce it by means of the reaction

$$\gamma + Li^7 \rightarrow H^5 + 2p, \; Q \approx -30 \text{ MeV}. \quad (1)$$

If H^5 does exist, it will decay to He^5 by β^- emission ($\approx$19 MeV) with a minimum half-life of about 10 msec.[2,3] Since all states of He^5 are unstable against neutron emission, H^5 would be a delayed-neutron emitter.

APPARATUS AND EXPERIMENTAL PROCEDURE

Neutrons were detected in a paraffin-moderated array of enriched BF_3 proportional counters. The efficiency of the detector was determined to be 0.83% by calibration with a mock fission source. The moderator was enclosed in a cadmium container to reduce the thermal neutron background, and the detector was enclosed in a 4-ft-thick shield of blocks containing a mixture of boric acid powder and paraffin.

The targets were combarded by γ rays from the Berkeley 340-MeV synchrotron. The bremsstrahlung beam was collimated by a lead collimator and then cleared of charged particles by passage through a magnetic field. Additional shielding was added to reduce the neutron background produced in the synchrotron and in the lead collimator. To minimize the number of neutrons produced by the photon beam, a thin-walled ionization chamber was used to monitor the number of photons passing through the targets. This chamber was

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[1] Conference on Photonuclear Reactions, held at Case Institute, Cleveland, 1958 (unpublished).
[2] G. W. Tautfest, Phys. Rev. **111**, 1162 (1958).
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calibrated against a standard "Cornell-type" thick-walled ionization chamber.

The synchrotron was adjusted to produce a short beam pulse and the repetition rate was 6 pulses/sec for most of the experiment. The parallel outputs of the BF_3 proportional counters were amplified and scaled in 14 delay channels which were variable in width and initial delay. The operation of the apparatus was checked by observing the delayed neutrons produced in the bombardment of a thick B_4C target. The resulting decay curve is shown in Fig. 1, where the straight line represents the 0.17-sec half-life of the delayed-neutron emitter, Li^9, produced in the reactions $B^{11}(\gamma,2p)Li^9$ and $C^{12}(\gamma,3p)Li^9$.[4,5] No attempt was made to measure an absolute cross section.

In this experiment, separated isotopes of Li^6 and Li^7 were used as targets. Photon bombardment of Li^6 cannot produce H^5, and so the counts observed during the bombardment of Li^6 were used as a measure of the background. Each target had the same thickness of 2.34×10^{23} nuclei/cm^2 and was sealed in a thin-walled aluminum container. The thickness of aluminum was the same for both targets. The setting of the initial delay to 150 μsec and the channel widths to 50 μsec permitted measurement of the decay curve resulting from the thermalization of the prompt neutrons. During this initial period ($\approx$1 msec) the neutron yield from Li^7 was observed to be 1.26 times as great as the yield from Li^6.

Following the initial decay associated with the thermalization of the prompt neutrons, a residual counting rate was observed for both targets. Target-out background runs indicated that these counts were being produced by the targets. As the bombardment of Li^6 cannot produce a delayed neutron emitter, an Al target was bombarded to determine whether the background counts were due to the thin aluminum target containers. The increased counting rate observed with the Al target indicated that about one-third of the residual counting rate from the Li targets could be attributed to their Al containers. Further investigation with the Al target showed that the lifetime associated with this activity was 4 sec, and therefore these delayed neutrons resulted

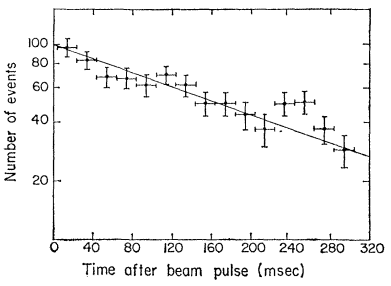

FIG. 1. Delayed neutrons produced in the bombardment of a B_4C target with 340-MeV bremstrahlung. The line represents the 0.170-sec half-life of Li^9 produced in the reactions $B^{11}(\gamma,2p)Li^9$ and $C^{12}(\gamma,3p)Li^9$.

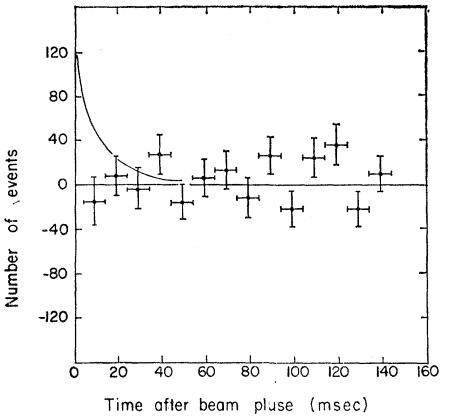

FIG. 2. Residual delayed neutrons produced in the bombardment of the Li^7 target following the subtraction of the Li^6 background. The number of effective quanta used to produce these events was $Q_e=2.18\times10^{12}$. The curve shows the assigned upper limit for H^5 production assuming a 10-msec half-life.

from the production of N^{17} in the reaction

$$\gamma+Al^{27}\rightarrow N^{17}+2\alpha+2p. \quad (2)$$

The remaining two-thirds of the residual counting rate we assume was due to the production of delayed neutron emitters in the detector assembly by the fast neutrons produced in the Li targets. We also assume the activation cross sections to be proportional to the number of neutrons in the Li nuclei. This implies a Li^7:Li^6 ratio of 4/3. If we average neutron production and N^{17} production from the aluminum containers, we obtain, for the final Li^7:Li^6 target background ratio,

$$1/3\times1+2/3\times4/3=1.22.$$

This compares with the 1.26 observed in the first msec after the beam pulse as noted above. The factor 1.22 was the one actually used to normalize the Li^7 background to the Li^6 background for the subtraction shown in Fig. 2.

This Li^7-Li^6 subtraction technique constitutes an important improvement over the experiment of Tautfest. In that experiment the background was measured by replacing the Li target of natural isotopic abundance with a copper absorber of the same thickness in radiation lengths.[2]

RESULTS AND DISCUSSION

Figure 2 shows the results of the Li^7-Li^6 subtraction for a 4-msec initial delay and a 10-msec channel width. The number of effective quanta used to produce these events was

$$Q_e=2.18\times10^{12},$$

where

$$Q_e=\int_{k_t}^{k_0}\phi(k,k_0)dk,$$

[4] F. Ajzenberg-Selove and T. Lauritsen, Nuclear Phys. **11**, 1 (1959).

[5] G. W. Tautfest, Phys. Rev. **110**, 708 (1958).

in which k_t is the 30-MeV threshold for reaction (1), k_0 is the peak energy of 340 MeV, and $\phi(k,k_0)$ is the photon distribution function. Note that the data show no apparent lifetime and that, in fact, they fall uniformly about zero. If one assumes a 10-msec half-life, and that the upper limit for H^5 production is given by four standard deviations above the first point, then one obtains the solid curve shown in Fig. 2 from the amount of H^5 that should be observed. This curve gives an upper limit for the activation cross section for reaction (1) of

$$\sigma_A \leq 3\times 10^{-32}\ \text{cm}^2,$$

where

$$\sigma_A = \frac{1}{Q_e}\int_{k_t}^{k_0} \sigma(k)\phi(k,k_0)dk.$$

This activation cross section is only 1/500 of that of the reaction

$$\gamma + B^{11} \rightarrow Li^9 + 2p,\ Q = -31.3\ \text{MeV}, \qquad (3)$$

and 1/3500 of that of the reaction

$$\gamma + F^{19} \rightarrow N^{17} + 2p,\ Q = -23.5\ \text{MeV}, \qquad (4)$$

as measured by Tautfest at 320 MeV.[5] It is difficult to determine how to extrapolate the activation cross sections of reactions (3) and (4) to reaction (1). According to Levinger and Bethe, the *total* activation cross section should be proportional to $A^{5/3}$.[6] If we quite arbitrarily assume that the activation cross sections of reactions (3) and (4) are related by a power law in A, then Tautfest's measurements indicate that they must be proportional to $A^{7/2}$. If we extrapolate this result to reaction (1), it should have an activation cross section about 1/5 that of reaction (3). Thus, by this estimate, the upper limit of the activation cross section for reaction (1) is about two orders of magnitude less than expected.

Even though our method of estimating the activation cross section of reaction (1) is crude, our experimental result is so small that we nevertheless conclude, in agreement with Tautfest, that H^5 is not stable against particle emission.

Note added in proof. Our attention has recently been called to a paper by V. I. Gol'danskii, Soviet Phys.—JETP **11**, 1179 (1960), in which the author shows by a detailed consideration of the neutron pairing energies that, contrary to reference 3, H^5 in fact cannot be stable against nucleon emission.

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[6] J. S. Levinger and H. A. Bethe, Phys. Rev. **78**, 115 (1950).