sections over the 1–30 Mev energy range for the elements listed in Table I is given in Figs. 1–11. As an aid in interpolating between these results, Fig. 12 summarizes the neutron nonelastic collision cross-section measurements on some 23 elements at a single energy, 14 Mev.[1]

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Search for Delayed Neutrons from the Photon Bombardment of Lithium*

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A search has been made for delayed neutrons resulting from the reaction $Li^7(\gamma,2p)H^5$ in an effort to decide whether or not H^5 exists. Delayed neutrons were detected in a moderated counter assembly and scaled in nine delay channels which were variable in width and initial delay. A small signal observed after background subtraction showed no decay within statistics over a period of 0.45 sec. The first 0.05-sec counting period has been analyzed for the presence of a decay of 0.01-sec half-life and compared with a predicted yield of the reaction $Li^7(\gamma,2p)$ obtained by extrapolation of the measured yields of the reactions $B^{11}(\gamma,2p)$ and $F^{19}(\gamma,2p)$. The conclusion is that less than one percent of the expected $Li^7(\gamma,2p)$ yield can result in a particle stable final state.

I. INTRODUCTION

THE known delayed-neutron emitters among the light nuclei, Li^9 and N^{17}, belong to the nuclear species of the form $Z=2N-1$, $A=4N+1$. Of the other members of this series, B^{13} has recently been shown to exist[1] but no neutrons have been observed from its decay, and delayed-neutron emission from F^{21} is known to be energetically forbidden.[2] Searches have been made without success for other members of the series or for other unknown delayed-neutron emitters formed as a result of spallations induced by high-energy particles[3] and photons.[4] Attention has recently been drawn to the first member of the series described above by the suggestion[5] that H^5 might be particle stable. If so, H^5 would decay by energetic β^- emission ($\sim$19 Mev) to He^5, all states of which are unstable against neutron emission. The transition would be first-forbidden since the ground level of H^5 would be $(\frac{1}{2},+)$, while the ground level and first excited level of He^5 are odd. With outside limits on the mass and the ft value, one finds a minimum possible half-life of 0.01 sec.

Analysis of the previous searches in this region,[3,4] indicate that because of the targets chosen or the detection-sensitivity employed, detectable quantities of H^5, if particle stable, would probably not have been formed.

In this paper we present the results of a search for the delayed neutrons which would accompany the decay of H^5 formed by the reaction $Li^7(\gamma,2p)H^5$ if H^5 were particle stable.

II. EXPERIMENTAL PROCEDURE

The apparatus used was identical to that employed to measure the delayed-neutron yield from the photoproduction of Li^9 and has already been described in detail.[6] Neutrons are detected in a moderated array of enriched BF_3 proportional counters and scaled in nine delay channels following the photon burst from the Purdue University Synchrotron. The absolute neutron detection efficiency was determined with the aid of the Argonne National Laboratory standard Ra-Be working source.[7] Bremsstrahlung of peak energy 320 Mev bombarded a lithium target which was of natural isotopic abundance and 22.9 g/cm² thick. The beam was monitored with a "Cornell-type" thick-walled ionization chamber. The background was measured by replacing the lithium target with a copper absorber of the same thickness in radiation lengths.

The result of a first series of runs was a large delayed-neutron signal which varied linearly with target thickness and which had a half-life of 170 milliseconds. This signal was initially believed to be due to Li^9 formed from a contaminant in the target but the amount of contamination required to explain the observed yield was

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[7] We are indebted to Dr. E. W. Phelan of the Argonne National Laboratory for his assistance in arranging for the loan of this source and some of the BF_2 counter used in this experiment.

grossly inconsistent with the measured purity of the target. Increasing the copper-absorber thickness to the same number of g/cm^2 present in the lithium target reduced the signal to one-half that previously observed. The conclusion was reached that the signal was largely, if not entirely, the result of the reaction $C^{12}(n,n'3p)Li^9$ taking place in the paraffin moderator in use at that time as a result of the fast-neutron yield from the lithium target. This hypothesis is not in disagreement with calculations based on a fast-photoneutron yield determined from the known yields of high-energy photoprotons and the quasi-deuteron model of the process. Most convincing is the fact that the signal disappeared when the paraffin moderator was replaced with a water moderator.

Runs with the water moderator were made with an initial delay after the beam pulse of from ten to thirty milliseconds and with gate widths of from five to fifty milliseconds.

III. RESULTS AND DISCUSSION

A total integrated beam intensity of 2.1×10^{12} equivalent-quanta was used in the experiment with the water moderator. Counts above background were observed (Table I) with no decay evident over a period of 450 msec within the 15% statistics obtained after background subtraction. The observed signal is consistent with the $O^{18}(n,n'p)N^{17}$ reaction taking place in the water moderator. The data have been analyzed to place an upper limit to the amount of H^5 decay which might be masked by the observed yield. If three times the standard deviation of the counts occurring in the first 50 msec counted after the beam pulse is attributed to a H^5 decay with half-life equal to 10 msec, an activation cross section equal to 2.8×10^{-32} cm^2 is obtained for a peak bremsstrahlung energy of 320 Mev. Activation cross section is defined as

$$A(k_0)=\int_{k_t}^{k_0}\sigma(k)\phi(k,k_0)dk, \tag{1}$$

where $\sigma(k)$ is the reaction cross section at a photon energy k having a threshold at photon energy k_t and $\phi(k,k_0)$ is the photon distribution function for a peak bremsstrahlung energy k_0. If this cross section is analyzed on the basis of a narrow resonance centered at 40 Mev, the limit obtained for the integrated cross section of the $Li^7(\gamma,2p)H^5$ reaction is

$$\int^{320\text{ Mev}}\sigma(k)dk\leq 8.7\times10^{-31}\text{ Mev cm}^2. \tag{2}$$

TABLE I. Summary of data in 50-millisecond channels.

Channel No.	Lithium target No. of counts	Copper target No. of counts	Net signal No. of counts
1	617	391	226±32
2	581	400	181±31
3	610	366	244±31
4	588	354	234±30
5	576	372	204±31
6	563	331	232±31
7	530	365	165±30
8	511	330	181±27
9	529	313	216±27

This procedure may seriously underestimate the integrated cross section if, in addition to the low-energy resonance, the cross section has a high-energy tail. An extreme form for such a tail may result if the cross section increases for energies above 120 Mev because of mesonic effects. Such a "meson-rise" is observed for photonuclear processes in other nuclides.[6,8] If we assume that the activation cross section is *entirely* due to a cross section increasing linearly with energy from 120 Mev to a maximum, σ_m at 320 Mev, the result is

$$\sigma_m=6.8\times10^{-32}\text{ Mev cm}^2,$$
$$\int^{320\text{ Mev}}\sigma(k)dk\leq 6.8\times10^{-30}\text{ Mev cm}^2. \tag{3}$$

It is more difficult to determine what this upper limit should be compared with. The expected cross section cannot be estimated from sum-rule considerations[9] since the measurement is taken well above the region where meson effects begin to become important. An estimate of the expected integrated cross section may be obtained by extrapolation of the observed $(\gamma,2p)$ yields from other nuclei at 320 Mev.[6,8] It has been noted[6] that the ratio of the cross sections integrated up to 320 Mev of the reactions $B^{11}(\gamma,2p)Li^9$ and $F^{19}(\gamma,2p)N^{17}$ is unity if they are normalized to the quantity NZ/A. If we assume that this ratio will hold in the case of the $Li^7(\gamma,2p)$ reaction then we estimate the cross section integrated to 320 Mev should be at least 1.2×10^{-27} Mev cm^2. This is fourteen-hundred times the upper limit allowed by (2) and two-hundred times the upper limit allowed by (3). It appears unlikely from these considerations that H^5 is particle stable.

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