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Search for a Long-Lived H^4†

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A search is made for the β decay of a long-lived H^4, produced by 250-MeV bremsstrahlung in lithium of natural isotopic abundance. No evidence for such a long-lived isotope is found. This corresponds to the following upper limits for the production cross section: $\sigma_p < 6.7\times10^{-4}$ μb, assuming that the half-life of H^4 is 3 min, and $\sigma_p < 2.3\times10^{-4}$ μb, assuming the half-life is 1000 min. The β detector is also sensitive to gamma rays, but no evidence for delayed gamma rays is found.

I. INTRODUCTION

IN a recent paper Werntz and Brennan[1] have predicted the existence of a bound H^4. Their prediction is based on calculations that involve the following phenomena:

a. An excited state of He^4 at 20 MeV with spin and parity assignments $J=0^+$.[2,3]
b. New low energy H^3-p scattering data.[4]
c. Evidence for a nucleon-stable H^5.[5]

This bound H^4 is the $T_3=-1$ component of the isotopic spin triplet of which the $T_3=0$ component is the excited state of He^4 at 20 MeV. Thus, H^4 has spin and parity assignments $J=0^+$. It should decay to the ground state of He^4 with the emission of a high energy electron, $E_\beta(\max)\simeq 20$ MeV. This is a highly unfavored $0^+\rightarrow 0^+$ transition. Werntz and Brennan[1] estimate that the β decay of H^4 should have a half-life of about 1 h.

Previous searches for the β decay of H^4 were designed on the hypothesis that H^4 was short lived,[6] except for the measurements of Imhof *et al.*[7] They have reported an upper limit of the cross section of the reaction $H^3(d,p)H^4$ $\sigma\leq 5\times10^{-3}$ μb, assuming a half-life of 100 sec, as well as an upper limit of the cross section of the reaction $H^3(n,\gamma)H^4$ $\sigma\leq 5\times10^{-2}$ μb assuming a half-life of 1 h.

We report here on the upper limit of the cross section of the production of a high energy β activity with a half-life in the range of 1–1000 min induced by high energy photons in a lithium target. The reactions considered are:

$$\begin{aligned}
&Li^7(\gamma,2pn)H^4, && Q=-31\text{ MeV},\\
&Li^7(\gamma,dp)H^4, && Q=-29\text{ MeV},\\
&Li^7(\gamma,He^3)H^4, && Q=-23\text{ MeV},\\
&Li^7(\gamma,p2n\pi^+)H^4\text{ etc.}, && Q=-171\text{ MeV},\\
&Li^6(\gamma,2p)H^4, && Q=-24\text{ MeV},\\
&Li^6(\gamma,pn\pi^+)H^4\text{ etc.}, && Q=-164\text{ MeV}.
\end{aligned}$$

These reactions allow the production of H^4 with either the assignments given by Werntz or other speculative assignments of spin, parity, and isotopic spin. We mention this because of a recent speculation by Argan and Piazzoli.[8] They suggest the existence of H^4 with $T=2$ in order to explain a strong angular correlation found in the photoproduction of π^+ on helium.[9] Most previous searches for H^4 were seriously restricted to certain assignments, particularly the $H^3(d,p)$ reaction, in which only $T=0$ and $T=1$ final states can be produced.

II. EXPERIMENTAL METHOD

A 99.83% pure lithium target of natural isotopic abundance was irradiated with 250-MeV bremsstrahlung from the University of Illinois betatron. The target was 10 in. long and 1 in. square, divided into 5 blocks, each 2 in. long and individually wrapped in 1-mil Mylar. The betatron beam was collimated to $\frac{3}{4}\times\frac{3}{4}$ in. All irradiations were 2 h long, except one that lasted

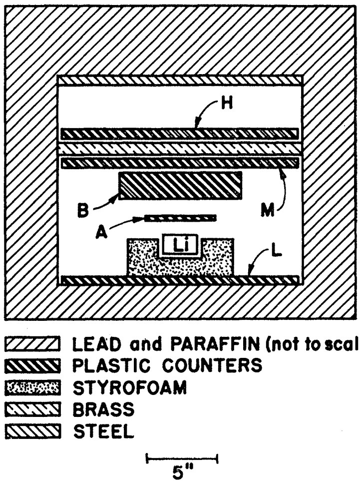

FIG. 1. β-Detector configuration.

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Table I. Experimental results of two runs.

Run number		IV	V
Irradiation time (min)		120	430
Total yield (effective quanta)		12×10^{12}	48×10^{12}
Background counts/min		0.45	0.45
Counting interval (min)	Counting time (min)	Total counts in $AB\bar{H}\bar{L}\bar{M}$	
1.5–11.5	10	4	
1.5–34.5	30	19	
1.5–98.0	90	45	
6.0–36.0	30		22
6.0–130.0	120		73
6.0–359.0	240		121

7 h. Within $1\frac{1}{2}$ min after the irradiation, the lithium was placed in a β detector and then counted for several hours in counting periods of 3, 10, 30, and 60 min. Background runs were taken before an irradiation, in-between and after the lithium counting periods.

The β detector, which was assembled from existing counters, is shown in Fig. 1. It consisted of 5 plastic scintillators in a coincidence and anticoincidence arrangement, designed to keep the cosmic ray background as small as possible. The β detector was located in a house made of lead and boron loaded paraffin. H and L are $14\text{-}\times14\text{-}\times\frac{1}{2}$-in. anticoincidence counters that eliminated most of the cosmic rays. A is a $3\frac{3}{4}\times3\frac{3}{4}\times\frac{1}{8}$-in. counter that was in coincidence with counter B, which has the dimension $6\frac{5}{8}\times7\times1\frac{1}{2}$ in. The trigger of A was set to accept all minimum ionizing particles, while the trigger of B was set—with the aid of a Co^{60} source—to count only particles of energy ≥ 2 MeV. A 1-in. brass plate was inserted to prevent energetic β's from reaching the anticounter H. The cosmic ray background in $AB\bar{H}\bar{L}$ was 2.5 counts/min. To reduce this further we inserted another anticounter M between B and the brass plate. The background in $AB\bar{H}\bar{M}\bar{L}$ was 0.45 counts/min. Of course, this anticounter M reduced the efficiency somewhat for the β's from H^4. To check on the stability of the counters, and to have a versatile setup, we monitored all the singles and also counted HLM, the sum $(H+L)$, the sum $(H+L+M)$, AB, $AB\bar{H}\bar{L}$, and $AB\bar{H}\bar{M}\bar{L}$.

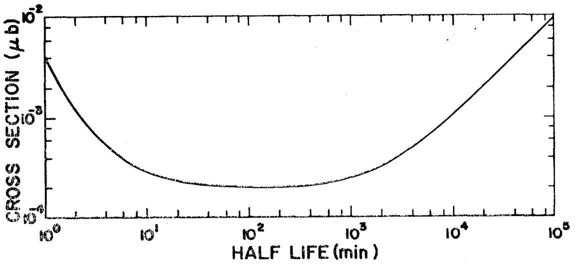

Fig. 2. Upper limit of the production cross section σ_p versus half-life of H^4.

III. EXPERIMENTAL RESULTS

The counts obtained from the lithium target in the scalers $AB\bar{H}\bar{M}\bar{L}$, $AB\bar{H}\bar{L}$, AB, and B (singles) are consistent within statistics with the counts recorded without target. The singles of A, L, and M showed a small increase in counting rate. The explanation of these increased single rates is the activity of C^{11}, O^{15}, N^{13}, etc., produced in the Mylar and in the impurities.

The solid angle Ω from AB was calculated to be of the order of 17%. The efficiency η for the expected β spectrum from H^4, with $E_\beta(\max)\simeq20$ MeV, originating from a 1-in.-thick lithium target, was estimated to be $\eta>20\%$ for $AB\bar{H}\bar{M}\bar{L}$.

The relevant data from two of the runs are shown in Table I. The counting time is the actual time the sample was counted. The counting interval includes the time in between counting used for recording of data and background measurements. The end of the irradiation is defined as 0.00 min. The total counts are those recorded in $AB\bar{H}\bar{M}\bar{L}$. The counts recorded in $AB\bar{H}\bar{L}$, AB and B (singles) give a result compatible with $AB\bar{H}\bar{M}\bar{L}$, but they have a larger uncertainty, due to the higher background.

The runs shown in Table I were used to calculate the upper limits for the production cross section σ_p of energetic β emitters produced by the bombardment of lithium with 250 MeV bremsstrahlung. Figure 2 shows the upper limits of the production cross section versus half-life of H^4. σ_p is defined by the equation:

$$A=N\times Q\times\eta\times\Omega\times\sigma_p,$$

where A is the number of radioactive nuclei produced, N is the number of Li atoms per cm^2, and Q is the number of effective quanta that was used to produce A. To

Table II. Production cross section for comparable reactions on light nuclei.

Reaction	E_γ (max)	σ_p in μb	$-Q$ in MeV	Ref.
$He^4(\gamma,pn)d$	170	200	26	c
$He^4(\gamma,2pn)$	170	26	28	c
$Li^7(\gamma,2p)H^5$	320	1.8	31	5
$B^{11}(\gamma,2p)Li^9$	320	37	31	d
$N^{14}(\gamma,2p)$	170	250	25	e
$(\gamma,2pn)$	170	200	28	e
$O^{16}(\gamma,2p)$	170	500	22	e
$(\gamma,2pn)$	170	240	30	e
$Ne(\gamma,2p)$	170	590	21	e
$(\gamma,2pn)$	170	200	29	e
$F^{19}(\gamma,2p)N^{17}$	320	100	24	f
$F^{19}(\gamma,2pn)N^{16}$	303	100	24	g
$Li(\gamma,\ )H^4$	250	$<5\times10^{-2}$ [a] $<2\times10^{-4}$ [b]		This work

[a] Assuming that the half-life of H^4 is 1 year.
[b] Assuming that the half-life of H^4 is 1 h.
[c] A. N. Gorbunov and V. M. Spiridonov, Zh. Eksperim. i Teor. Fiz. **33**, 21 (1957) [translation: Soviet Phys.—JETP **6**, 16 (1958)].
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achieve a high degree of confidence in the evaluated upper limits, we used for the computation of A the net number of counts (that is, target minus background) recorded in $AB\bar{H}\bar{M}\bar{L}$, plus *three times* the standard error in this net number.

Following a suggestion by C. Werntz,[10] we have calculated a lower limit of the half-life of H^4, assuming a modest production cross section $\sigma_p = 0.1$ μb. Our result for this lower limit is 2 years.

It may be noticed here that our setup, especially counter B, is also sensitive to gamma rays—but with a smaller efficiency. For instance, $\eta > 4\%$ for $2\frac{1}{2}$-MeV gamma's in counter B.

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[10] C. Werntz (private communication).

IV. CONCLUSION

The upper limits of the production cross section of H^4 from lithium are of the order of 2×10^{-4} μb, many orders of magnitude smaller than the cross sections of similar process in other elements, as shown in Table II. We therefore conclude that it is very unlikely that H^4 is a β emitter with a half-life ranging from 1 min to 2 years. It is also unlikely that H^4 should have a half-life longer than 2 years because that would give a log $ft \geq 14$ for its decay. It is clear that new decay schemes of a long-lived H^4 not discussed here (for instance, one that involves a hitherto undiscovered level in He^4) are also unlikely when we consider that no delayed gamma rays were observed.

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Alpha-Particle Resonance*

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A phase-shift analysis of the elastic p-t cross section in the energy range 0.1 to 0.76 MeV has been made. It is shown that the low peak observed at 0.3 MeV is consistent with a 0^+ resonance at 0.5±0.1 MeV. The shape of the observed cusp in the p-t elastic cross section at the threshold energy of the n-He^3 channel is used to demonstrate that the energy behavior of the singlet and triplet s-wave phase obtained must be qualitatively unique. A direct comparison is made of the Breit-Wigner single-level approximation and the alternative two-channel scattering length description of the state.

I. INTRODUCTION

A PEAK has been observed in the energy spectrum of breakup neutrons from the reaction $t(d,np)t$ in two separate high-resolution experiments.[1,2] The peak in the neutron distribution corresponds to an energy of 0.5 in the center of mass of the t-p system. The peak is most pronounced in the forward direction, disappearing entirely at about 60° in the laboratory. Such a distribution is typical of a stripping process in which the nucleon which interacts most strongly with the target nucleus interacts principally in an S state. The shape of the neutron peak can be fit fairly well[3] by assuming an S-wave resonance in the t-p system at an energy of about 0.5 MeV. The excitation energy of this state is 20.4 MeV with respect to the He^4 ground state.

However, as Watson has shown,[4] in a three-body breakup one can expect peaks in the spectrum of one of the fragments even when the important phase shift of the remaining two-body system does not have a resonance behavior. The only requirement is that this phase shift be a rapidly varying function of energy. Near a threshold this rapid variation can be due to a large scattering length. For example, a distinct peak is observed in the neutron spectrum from $d(p,pp)n$ due to the strong singlet S-wave interaction of the two protons. In order to determine whether one of the S-wave phase shifts actually passes through 90°, we have undertaken a phase-shift analysis of the differential cross section for elastic t-p scattering which has been recently measured by Jarmie *et al.*[5] in the energy region 0.16 to 0.52 MeV.

The cross section was measured at a single angle of 120° in the center of mass. A low peak appears at about 0.3 MeV, which corresponds to the peak observed in the $t(d,np)t$ reaction. In the elastic scattering it is shifted to slightly lower energy because of the different energy dependence of the kinematic factors in the two-body elastic scattering as compared to the three-body final state. The presence of a large Coulomb amplitude in the elastic scattering also has the effect of making the peak less prominent. In the sections which follow the attempt to obtain the $^1S_0$ and $^3S_1$ phase shifts is discussed. For both S-wave phase shifts the effect of the closed n-He^3

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