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# Search for an Excited State of the Triton[†]

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Upper limits for the formation of particle-stable and particle-unstable excited states of the triton in the reaction $\pi^-+{}^6\text{Li}\rightarrow{}^3\text{H}+{}^3\text{H}^*$ are given.

## INTRODUCTION

THE reported observation by Ajdačić *et al.*[1] of a particle-stable trineutron has prompted a search by several groups[2–6] for analog states in $^3$He. While Kim *et al.*[2] report the formation of two such states in inelastic proton scattering on $^3$He, other observers find no supporting evidence in ($^3$He, $^4$He)[4] and ($^3$He, $^3$He)[5] scattering experiments. A repetition of the proton scattering experiment[6] with increased sensitivity failed to confirm Kim's results. Since the existence of a trineutron would also imply the existence of a $T=\frac{3}{2}$ state of the triton, we have looked for the latter in the reaction

$$\pi^-+{}^6\text{Li}\rightarrow{}^3\text{H}+{}^3\text{H}^*. \qquad (1)$$

## EXPERIMENT

A schematic of the experimental layout is shown in Fig. 1. A negative pion beam from the 600-MeV synchrocyclotron at the Space Radiation Effects Laboratory (SREL) of the National Aeronautics and Space Administration in Newport News, Virginia, was stopped in a thin (60 mg/cm$^2$, 10×10 cm) $^6$Li target. Charged particles emitted by the target were registered on one side in a counter telescope consisting of the scintillation counters Sc5 and Sc6 and on the other side in a single scintillation counter Sc7. A coincidence of these counters with a stop signal from the beam telescope, i.e., a $123\bar{4}567$ coincidence, was used to trigger the sonic spark chambers Sp1-Sp4 and a 30-gap range chamber similar to the one described elsewhere.[7] The particle coordinates in each of the four sonic chambers and the penetration depth into the range chamber were determined with the SREL on line computer (IBM 360-44) and were recorded on magnetic tape for a later statistical analysis.[8]

The amount of Al absorber in front of the range chamber was so chosen that tritons from the reaction

$$\pi^-+{}^6\text{Li}\rightarrow{}^3\text{H}+{}^3\text{H} \qquad (2)$$

stopped in the back of the chamber. Ground-state tritons ($^3$H) from reaction (1) could then be expected to stop in the earlier gaps of the range chamber, depending on the energy of the excited triton $^3$H*. Particle-stable excited tritons must be collinear with the ground-state triton in order to conserve momentum. Particle-unstable triton states decay into either $^2$H$+n$ or $p+2n$ depending on their energy and isospin.

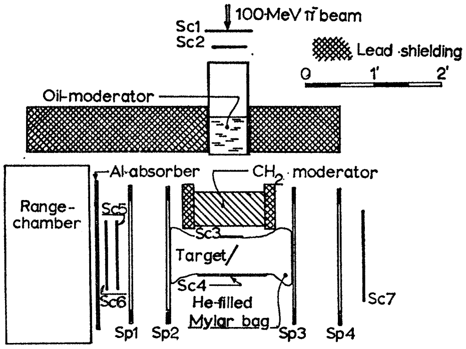

FIG. 1. Schematic view of the apparatus.

The decay proton or deuteron must in this case fall into a cone whose opening angle with respect to the triton trajectory is determined by the excitation energy. Our method is thus obviously suitable for the detection of both particle-stable and particle-unstable excited states. The results of our search are shown in Figs. 2 and 3.

## RESULTS

Figure 2 shows the range distribution of particle pairs with a 180° correlation. The ground-state triton peak is very pronounced. Its location agrees with that obtained from range curves[9] to within less than 0.2 MeV. The upper limit for the branching ratio with

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[8] In determining the range we corrected for the penetration angle, defining as the corrected range the gap in which a particle would have stopped had it travelled perpendicular to the range-chamber plates. The range distribution shown in Fig. 2 gives this corrected range.

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which $^3H^*$ is formed, and the method by which this branching ratio is obtained from our data varies with the excitation energy $E$ assumed for the $^3H^*$. We distinguish between four different regions (see Fig. 3). (a) In the region $0 \leq E \leq 1$ MeV it is not possible to distinguish $^3H^*$ from ground state $^3H$ and it is possible to attribute any fraction of the observed branching ratio of $(3.4 \pm 0.5) \times 10^{-4}$ for the main peak in Fig. 2 to the formation of $^3H^*$ with $E < 1$. (b) In the region $1 < E \leq 4$ MeV the existence of an $^3H^*$ peak would broaden the observed peak in Fig. 2. We have calculated the width of this peak for one infinitely narrow level using a Monte Carlo procedure to account for the effects of target thickness, range straggling and the variation in the thickness of the scintillators Sc5 and Sc6. This calculated width agrees with the measured width. Assuming as an outside possibility that the width of a peak due to *one* level is actually 20% (the uncertainty of our Monte Carlo calculation) narrower than calculated we can attribute 20% of the observed width to a second level. Based on this assumption we have calculated the upper limit shown in Fig. 3 for this region. (c) In the region between 4 and 6.25 MeV (the limit of particle stability) an excited state should show up as a separate peak in Fig. 2. From the absence of such a peak we derive the upper limit for the branching ratio given in Fig. 3 for this region. (d) In the region of particle instability above $E = 6.25$ MeV the deuteron from the decay $^3H^* \rightarrow {}^2H + n$ and the proton from the decay $^3H^* \rightarrow p + 2n$ (above $E = 8.48$ MeV) will fall within a cone whose opening angle increases with the decay energy. At the same time, the finite lifetime of a particle-unstable state would broaden any peak in the energy distribution. This results in the increase in the upper limit for the branching ratio shown in Fig. 3 for this region.

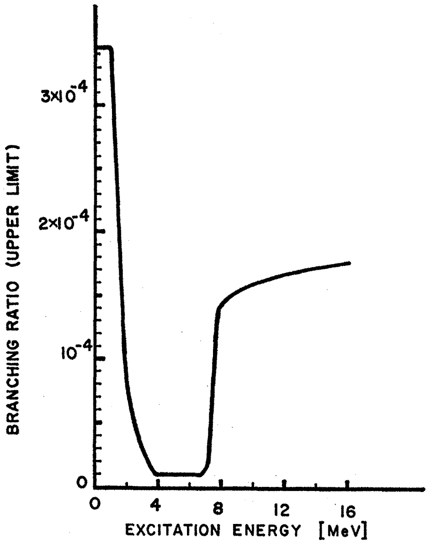

FIG. 3. Upper limit of the branching ratio for the formation of $^3H^*$ as a function of energy. An excited state formed with the branching ratio indicated by the curve would have given a recognizable peak with a probability of 95%.

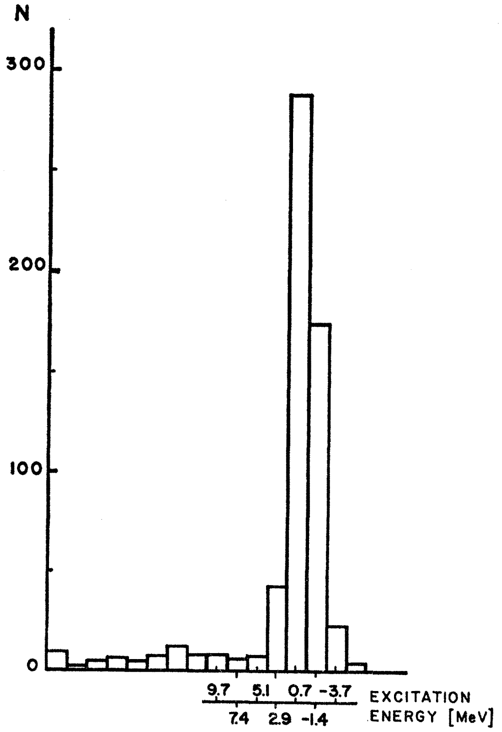

FIG. 2. Energy distribution of collinear charged particles.

## DISCUSSION

It is not possible to compare the upper limits set in our experiment with those obtained from scattering experiments without making a detailed theoretical analysis involving many assumptions It should, however, be pointed out that the branching ratio for the reaction (2) $(3.4 \times 10^{-4})$ is of approximately the same size as the branching ratio[10] for the reactions $\pi^- + {}^7Li \rightarrow {}^3H + {}^4H$ and $\pi^- + {}^7Li \rightarrow {}^3H + {}^4H^*$. This seems to indicate that the nuclear breakup, following pion capture, into fragments of approximately equal mass does not depend very critically on the quantum numbers of the final state. We believe, therefore, that the nonoccurrence of the reaction $\pi^- + {}^6Li \rightarrow {}^3H + {}^3H^*$ with a branching ratio substantially smaller than that observed for similar reactions strongly implies the nonexistence of an excited state of the triton.

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