is doubly complicated through the existence of low-lying collective excitations. Absorption sets in at a lower energy so that the range, where a purely real potential can be used, is more restricted. Polarization effects, resulting from the virtual transitions to the collective excited states, can no longer be ignored, since they may considerably alter the range and strength of the real potential. Nevertheless a potential like (5) is still expected to be a good starting point for the study of these nuclei.

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Search for the Ground State of ^{5}H by means of the ^{3}H(t,p) Reaction*

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Proton spectra from the ^{3}H$(t,p)^5$H and ^{3}He$(t,p)^5$He reactions have been measured with a triton bombarding energy of 22.25 MeV. Narrow $T=\frac{3}{2}$ states in the $A=5$ system were not observed in either reaction. However, in the ^{3}H(t,p) reaction broad peaks appeared in the proton spectra at energies consistent with a ^{5}H state 1.8 MeV above the $t+2n$ mass. The possibility that this peak can be attributed to the ground state of ^{5}H is discussed.

The possible existence of a particle-stable ^{5}H nucleus has been the subject of a number of papers.[1] Theoretical estimates for the mass of the ground state of ^{5}H range from a suggestion that ^{5}H is particle-stable by 0.6 MeV[2] to predictions that the ground state is unstable by several MeV.[3] Most experimental attempts to observe ^{5}H have been sensitive only to a bound ^{5}H system. For example, searches for β^- or delayed neutron activity from the ^{7}Li$(p,3p)^5$H, ^{3}H$(t,p)^5$H, and ^{7}Li$(\pi^-,pn)^5$H reactions have yielded negative results.[1] Although one report of β^- activity from the ^{7}Li$(\gamma,2p)^5$H reaction has been made,[4] negative results were obtained when the experiment was repeated under only slightly different conditions.[5] The few previous experiments which permitted detection of unbound ^{5}H states provide only negative results. For instance, no evidence for narrow states in ^{5}H (bound or unbound) was found in a recent study of ^{8}B spectra from the ^{9}Be$(\alpha,{}^8\mathrm{B})^5$H reaction.[6] In another recent experiment a search was made for the ground state of ^{5}Be using the ^{3}He$(^3\mathrm{He},n)^5$Be reaction.[7] The results indicate that ^{5}Be lies at least 4.2 MeV above the ^{3}He$+2p$ mass, which suggests that ^{5}H is unbound by at least 2.1 MeV.

A firm limit on the stability of ^{5}H can be obtained from the fact that the ground state of ^{9}Li is stable with respect to heavy-particle emission. That is, ^{5}H cannot be bound by more than 8.55 MeV or ^{9}Li would be unstable to ^{5}H$+^4$He decay. In a recent study of the ^{3}H$(d,p)^4$H and ^{3}H$(t,d)^4$H reactions, Jarmie *et al.* report no evidence for a bound ^{4}H nucleus in the energy range 0–12.8 MeV below the $n+t$ mass.[8] Assuming then that ^{4}H is unbound and using the systematics of neutron pairing energies,[9] a less certain estimate of 2.9 MeV for the maximum binding energy of ^{5}H can be obtained.[10]

To form a state in ^{5}H in the vicinity of the $t+2n$ mass with the ^{3}H$(t,p)^5$H reaction, a triton beam energy of at least 17 MeV is required. In the present experiment a tritium-filled gas target was bombarded with 22.25-MeV tritons from the Los Alamos three-stage electrostatic accelerator, and the energy spectra of protons were observed at four angles. The detection system consisted of a ΔE gas proportional counter followed by a 1000-μm fully depleted surface-barrier E detector. The effective thickness of the proportional-counter gas was equivalent to 21 μm of Si. A second solid-state detector located immediately behind the E detector was used to reject protons which had sufficient energy (>12 MeV) to penetrate the E detector. After satisfying a coincidence requirement, the E and ΔE energy spectra were

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[10] In this calculation, the neutron pairing energy of ^{5}H is assumed to be less than that of ^{6}He (2.9 MeV).

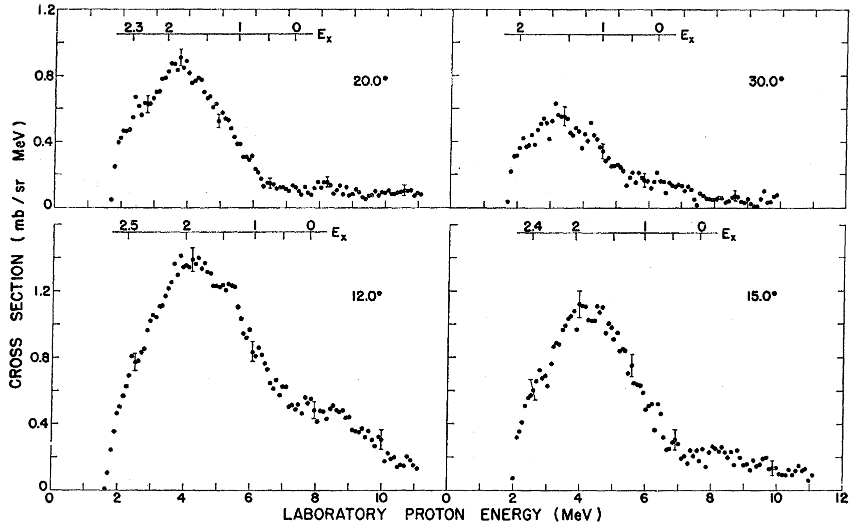

FIG. 1. Proton spectra from the $^3H(t,p)^5H$ reaction at laboratory angles of 12°, 15°, 20°, and 30°. The excitation energy scales are referred to the $t+2n$ mass.

recorded in two-parameter form and were analyzed with curve-fitting techniques in order to obtain optimum mass separation.

Proton spectra from the $^3H(t,p)^5H$ reaction at laboratory angles of 12°, 15°, 20°, and 30° are presented in Fig. 1. The excitation energy scale associated with each spectrum is referred to the $t+2n$ mass. The error bars represent statistical errors only. At energies below ~2 MeV, protons do not penetrate the ΔE detector, and the E-ΔE coincidence requirement results in a sharp cutoff in the spectra.

Because of a 5–10% hydrogen impurity in the tritium gas, a very intense elastic proton group penetrated the E detector at small angles. This impurity group was not completely eliminated by the rejection system and is responsible for a very small peak in the 20° spectrum at $E_{\text{lab}} \approx 8.2$ MeV and for at least some of the "fill" in the 12° spectrum near the $t+2n$ mass. Background corrections to the data include a target-empty background subtraction and a correction for slit-edge scattered protons from the elastic impurity group. The total background correction was of the order of 15% at the peak in the proton continuum. The residual background at energies above the $t+2n$ mass is thought to result from secondary reactions in the detector system induced by neutrons and tritons from the tritium target gas.

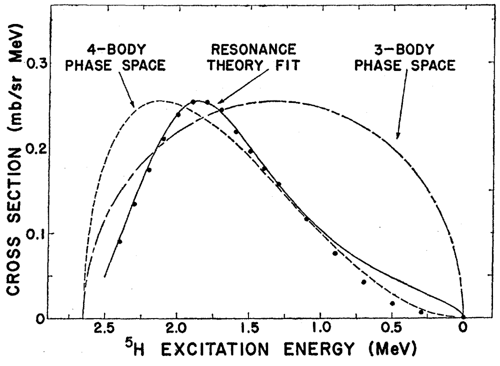

FIG. 2. Center-of-mass spectrum (points) at $\theta_{\text{c.m.}}=50°$ interpolated from laboratory spectra. The energy scale is referred to the $t+2n$ mass.

The cleanest spectra were obtained at $\theta_{\text{lab}}=15°$ and 20°. No evidence for narrow states attributable to ^5H is seen in these spectra for the excitation energy range +2.4 MeV to −2.7 MeV with respect to the $t+2n$ mass. In the energy range +0.5 MeV to −2.7 MeV an upper limit of 15 μb/sr can be placed on the cross section for the $^3H(t,p)$ reaction at 20° leading to a narrow ^5H state, assuming an experimental energy resolution of 0.15 MeV. From the data of Fig. 1, it appears likely that if ^5H exists, it is unbound by at least 1.8 MeV.

The prominent feature of the spectra of Fig. 1 is a broad peak (~1.2 MeV FWHM) occurring at 1.8 MeV above the $t+2n$ mass. This peak is investigated further in Fig. 2 where the points represent a center-of-mass spectrum ($\theta_{\text{c.m.}}=50°$) interpolated from the four laboratory spectra of Fig. 1. The points go to zero at an energy corresponding to the $t+2n$ mass as a result of the subtraction of a constant background from the laboratory spectra. The choice of $\theta_{\text{c.m.}}=50°$ serves to emphasize the $\theta_{\text{lab}}=15°$ and 20° laboratory data in the interpolation. The computed 3- and 4-body pure phase-space distributions are compared to a resonance-theory fit of the data using the expression[11]

$$\frac{d^2\sigma}{d\Omega_p dE_p} \propto \frac{P(E_p)P(E_{2n-t})}{[E_\lambda-\gamma^2 S(E_{2n-t})-E_{2n-t}]^2+\gamma^4 P^2(E_{2n-t})},$$

where E_{2n-t} is the relative energy of the dineutron and triton (i.e., the excitation energy in ^5H), the P's are penetration functions, and S is the shift function (equal to zero for $l=0$ neutrons). The quantity E_p is equal to

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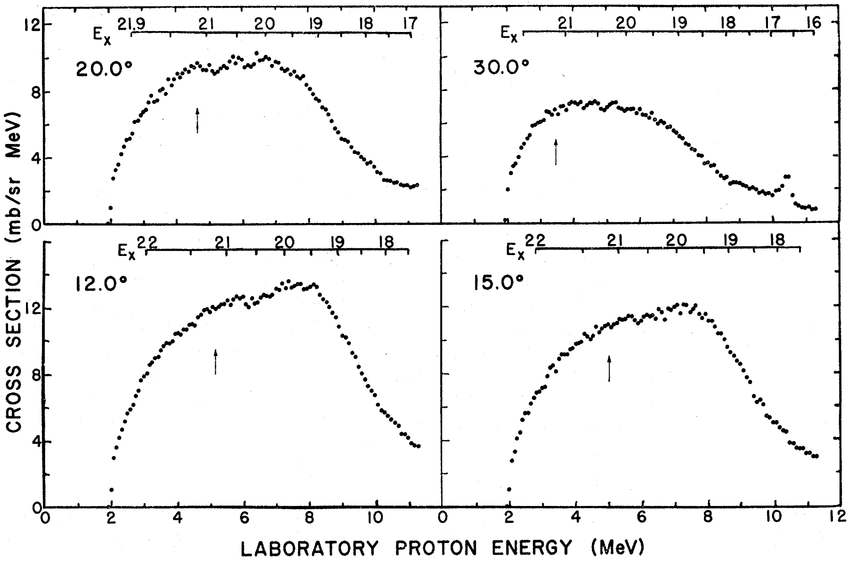

FIG. 3. Proton spectra from the ^{3}He$(t,p)^5$He reaction at laboratory angles of 12°, 15°, 20°, and 30°. The excitation energy scales are referred to the ground state of ^{5}He. The arrows indicate the energy of the broad peak observed in the ^{3}H(t,p) reaction after an appropriate Coulomb correction.

$\frac{1}{2}\mu v^2$, where $\mu = m_p(m_t+2m_n)/(m_p+m_t+2m_n)$, and v is the velocity of the proton relative to the $t+2n$ residual system. This expression is expected to describe the data if the observed peak results from a virtual state in ^{5}H, unstable to decay into a dineutron and triton. The parameters used in obtaining the fit are $l_p = l_{2n-t} = 0$, $a_p = a_{2n-t} = 3.0$ F, $E_\lambda = E_{\text{res}} = 2.15$ MeV, and $\gamma^2 = 0.7$ MeV. The three calculated curves have been normalized to the peak experimental cross section.

As is seen in Fig. 2, the resonance-theory curve fits the data quite well except at low energies relative to the $t+2n$ mass. The 3-body phase-space curve does not describe the results at all. Although the 4-body phase-space curve does not fit the data exactly, the difference is not exceedingly great. For instance, the 4-body phase-space curve reaches its maximum value within 300 keV of the experimental peak and is only about 25% greater in width. Therefore, the possibility that the observed peak is a phase-space effect cannot be excluded, and it is our conclusion that additional data are required to establish whether the peak observed in the present experiment corresponds to a state in ^{5}H. If the present experiment were repeated with a higher triton bombarding energy, then the maximum in the 4-body phase-space distribution would shift away from the distribution produced by a state of ^{5}H unbound by 1.8 MeV.

For the purpose of comparison, proton spectra were also obtained from the triton bombardment of ^{3}He gas, leaving ^{5}He as the residual nuclear system. Shown in Fig. 3 are the spectra measured at $\theta_{\text{lab}} = 12°$, 15°, 20°, and 30°. The excitation energy scale shown with each spectrum is referred to the ground state of ^{5}He. There is evidence for a very broad peak (presumably from a $T=\frac{1}{2}$ level) at an excitation energy of about 20 MeV. Similar effects at 20 MeV have been observed in the ^{7}Li$(p,{}^3$He$)^5$He reaction[12] and in d-T elastic scattering measurements.[13] The sharp peak observed in the $\theta_{\text{lab}} = 30°$ spectrum results from the 16.70-MeV state in ^{5}He. The arrows in Fig. 3 correspond to the position of the broad peak observed in the ^{3}H$(t,p)^5$H reaction after an appropriate Coulomb adjustment. The cross section is seen to be reasonably smooth in the vicinity of the arrows, and there is only a small hint of a peak in the 20° spectrum where the $T=\frac{3}{2}$ analog of the observed ^{5}H peak would be expected.

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