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OBSERVATION OF THE ^{3}He(p,n)3p REACTION AT 25 MeV[*]

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The neutron energy spectrum from the reaction ^{3}He(p,n)3p has been measured at a laboratory angle of 8° for a proton bombarding energy of 24.9 MeV. A deviation of the spectrum shape from the prediction for four-body phase space has been observed.

Recent studies [1-4] of the mirror reactions ^{3}He(p,n)3p and ^{3}H(n,p)3n have sought evidence for an enhancement near the four-body endpoint due to a three-proton or three-neutron interaction. These studies have been motivated by an intrinsic interest in the reaction mechanism leading to a four-body final state and by the possibility, admittedly remote, of detecting effects due to three-body forces.

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Previous work has set limits on the production of a triproton [2] or trineutron [4] system and provides rough values of the cross section for the formation of the four-body final state. Measurements of the $^3He(p,n)3p$ reaction have been made by Anderson et al. [1] at 14.1 MeV and 3°, and by Cookson [2] at 13.1 MeV and 20°. There is no evidence for a neutron group, below the four-body endpoint, corresponding to a triproton system which Anderson estimates would be unbound by 1.2 MeV on the basis of previous [3], but unconfirmed [4], work on the trineutron. Due to the extremely low neutron yield, no distinct neutron spectrum was observed and there is disagreement between the cross sections reported. Cookson quotes an estimate of the total cross section $\sigma_T = (5 \pm 18)\ \mu b$ at 13.1 MeV while Anderson et al. find a differential cross section $(d\sigma/d\Omega) = (0.5 \pm 0.3)$ mb/sr for neutron energies $3 \leqslant E_n \leqslant 5.85$ MeV at 14.1 MeV and 3°.

In the present experiment we have measured the neutron spectrum from the $^3He(p,n)3p$ reaction at a proton energy of 24.9 MeV. In contrast to previous work this energy is considerably above the reaction threshold (10.3 MeV). One expects a higher neutron yield if the cross section is essentially determined by the energy dependence of four-body phase space. The experimental setup is sketched in fig. 1. The proton beam from the Berkeley 88-inch cyclotron was focused at the center of a 15.2 cm long gas target held at a ^3He pressure of 1 atm by 6.2 mg/cm^2 Al entrance and exit windows. The neutrons were detected at a laboratory angle of 8° by means of a proton-recoil spectrometer. A 15 cm long, 6 mm diameter, brass collimator was used to define the neutrons from the target. A graphite absorber in front of this collimator was used to stop all charged particles. Protons recoiling from the 27.5 mg/cm^2

polyethylene radiator were detected and identified by a telescope consisting of three counters of thickness 140 μ, 300 μ, and 3 mm. A triple-coincidence requirement was used to reduce the number of random events caused by the neutron background and by (n,α) processes in the Si detectors. The sum of the pulses from counters ΔE_1 and ΔE_2 was used as the ΔE signal for particle identification [5] of the protons. The particle-identifier spectrum shown in fig. 1 represents a considerable improvement over previous experience [6] in this energy range with a two-counter system. It was verified that the energy spectrum of events above and below the window shown in fig. 1 did not fall within the limits of the observed proton-recoil spectrum.

The neutron background was measured by running the beam, for the same integrated charge, through a ^{4}He gas target, chosen because of the high threshold for neutron production (25.7 MeV) and the similar multiple scattering effect on the beam. The detection efficiency of the recoil spectrometer was measured with the ^{2}H(d,n)^{3}He reaction, at deuteron beam energies of 13.5 MeV and 11.6 MeV. The cross section was calculated from the Legendre coefficients given by Brolley _et al_. [7]. The efficiency for a neutron energy of 16.1 MeV (E_d = 13.5 MeV) was $\varepsilon = 2.8 \times 10^{-5}$. The energy resolution for 16.1 MeV neutrons was 0.80 MeV and was due primarily to the radiator thickness and the kinematic spread of the recoil protons. Measurements at the lower deuteron energy gave a value of ε consistent with the 1/E dependence of the n-p cross section in the radiator. The values of the cross sections quoted for the ^{3}He(p,n)3p reaction depend upon the accuracy of this calibration (estimated to be ± 15%).

The neutron spectrum from the ^{3}He(p,n)3p reaction at 8° is presented in fig. 2 for a total integrated charge of 43,000 μC. The measured spectrum (not shown) was corrected for the background contribution and the 1/E dependence of the spectrometer efficiency. The points shown correspond to sums of the real counts over intervals of 0.38 MeV. The error bars include the statistical errors for both the ^{3}He target spectrum and the ^{4}He target background. The spectrum covers a neutron energy range down to 8.5 MeV, corresponding to a 3p-excitation of 7 MeV. The total number of counts beyond the four-body endpoint (16.7 MeV) is consistent with zero. There is no evidence for a distinct neutron group corresponding to a strong interaction in the three-proton system. The four-body phase space prediction, indicated by the dashed curve in fig. 2 does not appear to account for the observed rise of the spectrum below the end point. A more satisfactory fit is obtained by considering the sequential reaction mechanism

$$p + {}^3\mathrm{He} \longrightarrow n + p + (2p)$$

in which the three-body phase space is weighted by a $^1S_0$ interaction between two protons in the final state [8]. The result, shown by the solid curve of fig. 2, has a shape more consistent with the trend of the experimental spectrum.

Integrating the spectrum over the energy range $8.3 \leqslant E_n \leqslant 16.7$ MeV gives a value for the cross section $(d\sigma/d\Omega) = (2.6\pm0.4)$ mb/sr. The assumption of a pure four-body phase space dependence gives a value for the total cross section at 24.9 MeV of $\sigma_T = 29$ mb. If this result is scaled with energy according to a four-body phase space behavior, one obtains a total cross section of 92 μb at 13.1 MeV; i.e., considerably higher than the upper limit of 23 μb set by Cookson [2]. This disagreement can be understood on the basis of our previous remark that the spectrum shape in the region below the endpoint deviates from the phase space prediction.

In summary, the neutron energy spectrum from the reaction ^{3}He(p,n)3p has been observed at a proton energy of 24.9 MeV and 8°. The departure of the spectrum from four-body phase space is tentatively explained as due to a $^1S_0$ final-state interaction between two protons. In view of these results it is clearly of interest to study this reaction at higher energies [9] with particular attention to the forward angles. It is clear that the nature of the reaction mechanism leading to the four-body final state must be understood before departures from phase space can be attributed unambigously to an interaction in the three-nucleon system. However, at present, reactions of this type offer the only practical way of investigating the properties of the $T_Z = \pm 3/2$ members of the mass-3 isospin quartet.

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References

1. J. D. Anderson, C. Wong, J. W. McClure, and B. A. Pohl, Phys. Rev. Letters 15 (1965) 66.
2. J. A. Cookson, Phys. Letters 22 (1966) 612.
3. V. Ajdačić, M. Cerineo, B. Lalović, G. Paić, I. Šlaus, and P. Tomaš, Phys. Rev. Letters 14 (1965) 666.
4. S. T. Thornton, J. N. Bair, C. M. Jones, and H. B. Willard, Phys. Rev. Letters 17 (1966) 201, and references therein.
5. F. S. Goulding, D. A. Landis, J. Cerny, and R. H. Pehl, Nucl. Instr. 31 (1964) 1.
6. R. J. Slobodrian, H. Bichsel, J. S. C. McKee, and W. F. Tivol, Phys. Rev. Letters 19 (1967) 595.
7. J. E. Brolley, T. M. Putnam, and L. Rosen, Phys. Rev. 107 (1957) 820.
8. In this calculation the neutron energy spectrum is expressed by

$$d^2\sigma/dE_n d\Omega \;\alpha \int_0^{E_{max}} \rho(E_n,E_{2p}) \left[\frac{C\, k_{2p}}{\left(-\frac{1}{a} + \frac{1}{2} r_0 k_{2p}^2 - \frac{h(\eta)}{R} P r_0^3 k_{2p}^4\right)^2 + C^2 k_{2p}^2} \right] dE_{2p}$$

   where E_{2p} is the excitation in the 2p-system, $\rho(E_n,E_{2p})$ is the three-body phase space term, the second term is the expression for the $^1S_0$ interaction in effective range theory, and E_{max}, the upper limit of the integral, is a function of E_n and E_{2p}.
9. At the time of writing this paper preliminary reports (see C. J. Batty et al., Rutherford Laboratory Report, RHEL/R170 (1968) 78) of measurements at a proton energy of 50 MeV indicate a significant departure from phase space of the neutron spectrum at forward angles.

Figure Captions

Fig. 1. (top) The experimental setup showing the gas target and the proton-recoil spectrometer at 8°. The diameter of the brass collimator is shown enlarged by a factor of 3.

Fig. 1. (bottom) The particle identifier spectrum for the recoil protons showing the window for accepted events.

Fig. 2. The neutron energy spectrum from the ^{3}He(p,n)3p reaction at 24.9 MeV and 8°. The dashed curve corresponds to the four-body phase space prediction. The solid curve corresponds to three-body phase space weighted by a $^1S_0$ interaction between two protons. The vertical scale is proportional to $d^2\sigma/dEd\Omega$.

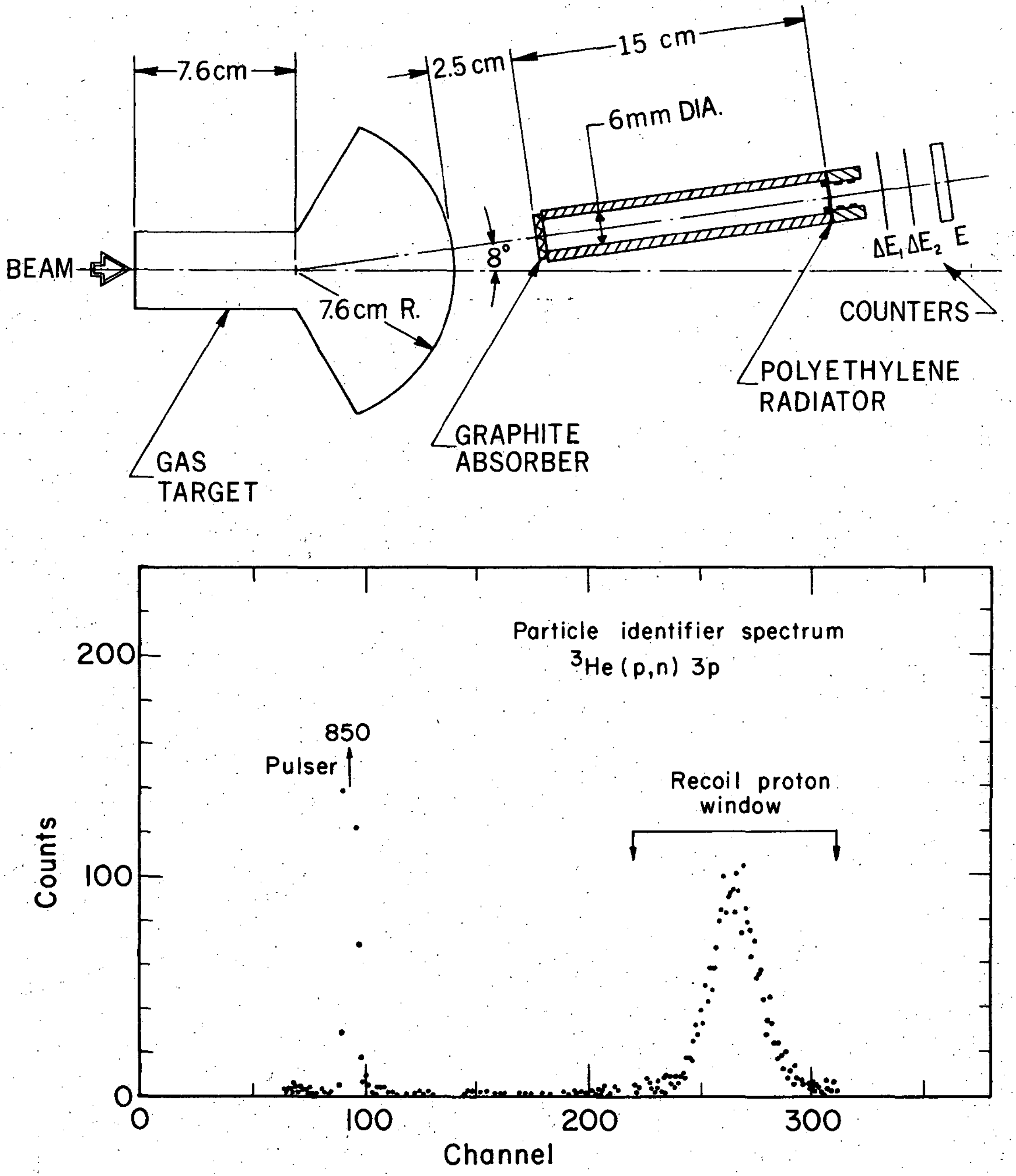

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Fig. 1.

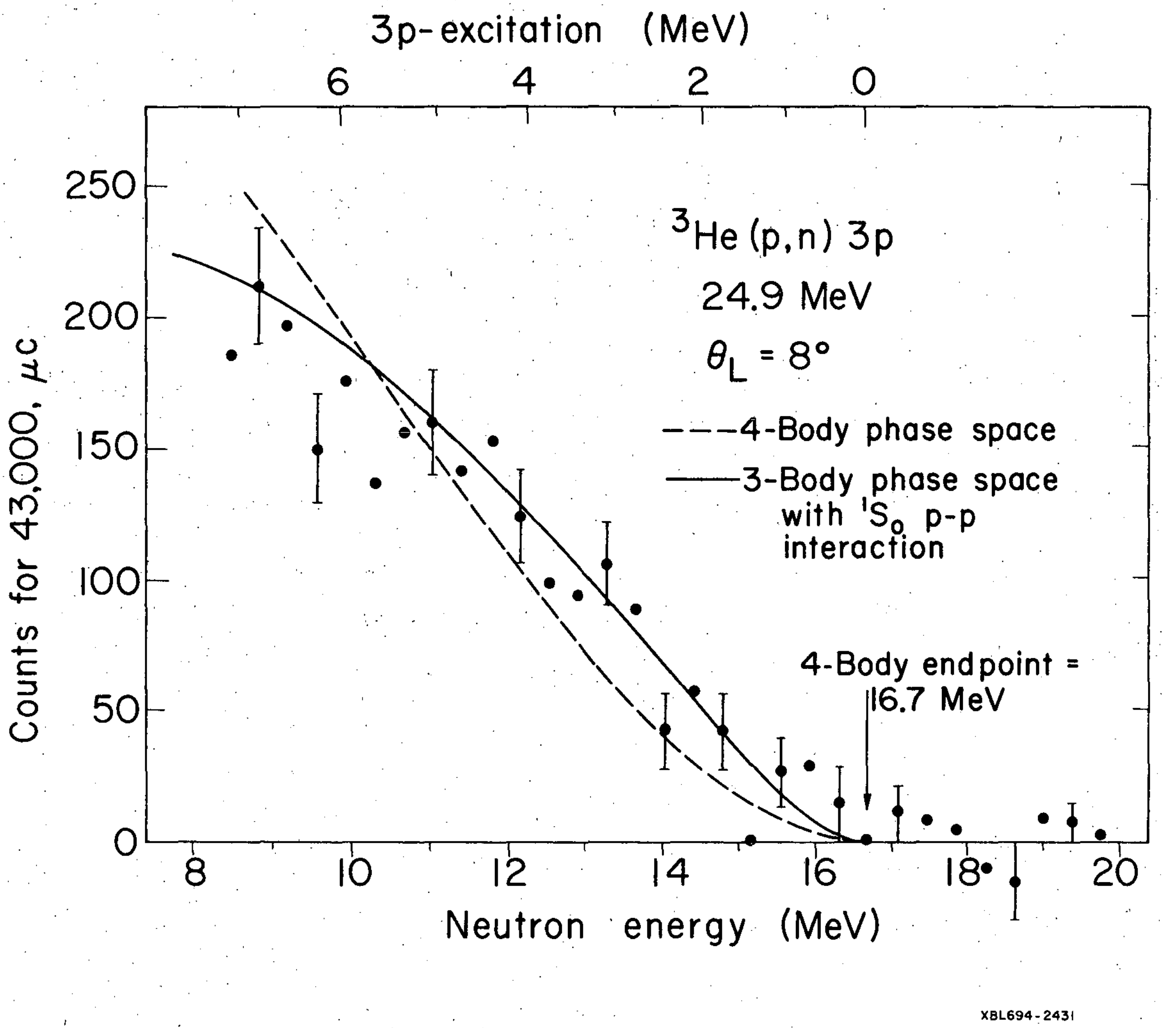
3p-excitation (MeV)
6
4
2
0
250
200
150
100
50
0
Counts for 43,000, μc
^{3}He (p,n) 3p
24.9 MeV
θ_L = 8°
4-Body phase space
3-Body phase space with $^1S_0$ p-p interaction
4-Body endpoint = 16.7 MeV
8
10
12
14
16
18
20
Neutron energy (MeV)
XBL694-2431

Fig. 2.

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