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Recent letters have reported experimental determinations of triton energy spectra from the $He^3(d,t)$ reaction at E_d = 28 MeV[1] and at 20 and 25 MeV.[2] The spectra of reference 1 were obtained with approximately 1.25-MeV energy resolution and a broad peak near the high energy end was interpreted as resulting from the formation of an unbound state of He^2 with a mean lifetime $\tau = (0.2 \pm 0.1) \times 10^{-21}$ sec. The observed angular variation of the peak was consistent with a pick-up reaction mechanism. The spectra of reference 2 were obtained with an energy resolution of about 0.5 MeV and consisted of continuum spectra with broad asymmetrical peaking near the high energy limit. These authors noted a resemblance to neutron spectra from the $D(p,n)2p$ reaction[3,4] whose shape was explained in terms of a final-state interaction[5,6] between the two protons, and they pointed out the necessity both for more precise data and for quantitative calculations in the continued investigation of this $He^3(d,t)2p$ reaction.

results

We report here experimental along with calculations based on the 2p final-state interaction interpretation, and we believe this to be the proper explanation of our data.

Triton spectra were measured with an energy resolution of approximately 120 keV at deuteron energies of 24.7 and 33.4 MeV, using the variable-energy Berkeley 88-inch cyclotron. Measured beam ranges in aluminum were converted to energies.[7] The counter assembly consisted of two silicon detectors, a ΔE and E set, with collimation which provided an angular resolution of 0.4 degree. Pulses from these detectors were fed into a particle-identifier system,[8] the

output of which was used to gate on a 400-channel pulse-height analyser whenever a triton identification occurred. The added ($\Delta E + E$) triton pulse spectrum was then displayed on the analyser. Also, triton spectra from the $N^{14}(d,t)N^{13}$ reaction were obtained for the purpose of calibration of the energy scale, which we believe to be accurate within 100 keV. Figure 1A contains a typical identifier spectrum, and Fig. 1B shows a triton spectrum at $\theta_L = 6.75^\circ$ taken at 24.7 MeV. Figure 2 exhibits a spectrum at $\theta_L = 8^\circ$ taken at 33.4 MeV. The observed differential energy spectra are fitted with final state interaction theoretical curves. The particular form used for the calculations was that of Migdal,[5] in which the 2p wave function includes Coulomb effects, and for comparison we show that of Watson,[9] applicable in the absence of electrostatic effects. The center of mass differential cross section is given by

$$\frac{d^2\sigma}{dE d\Omega} = g(\theta)\,\frac{2\pi}{v}\,|T(E_{2p})|^2\,\rho(E_T) \qquad (1)$$

where E_{2p} is the relative energy of the two protons in their own center of mass system, E_T is the corresponding center of mass triton energy, $g(\theta)$ is an angular dependent factor peculiar to the reaction mechanism, v is the relative velocity of the initial particles, and $\rho(E_T)$ is the phase space factor of the observed particles, in this case the tritons. $T(E_{2p})$ is the transition matrix element, which gives the "enhancement" of the cross section due to the final state interaction (or correlation) of the two protons. In Migdal's treatment this is just proportional to $|\phi_{2p}(q)|$, the 2p wave function, where q is the relative momentum.

We have used the following expressions to fit our data

$$|T|^2 \propto \frac{C(\eta)\ (E_{2p})^{1/2}}{C^2(\eta)\ E_{2p} + \frac{\hbar^2}{m_p}\left[-\frac{1}{a_p} - \frac{h(\eta)}{R} + \gamma\ E_{2p}\right]^2} \qquad (2)$$

where $C(\eta) = 2\pi\eta/e^{2\pi\eta}-1$ is the so called Coulomb penetration factor, a_p is the scattering length, $\eta = e^2/\hbar v$ and $h(\eta) = \mathrm{Re}\,\frac{\Gamma'(-i\eta)}{\Gamma(-i\eta)} - \ell n\eta$, $R = \hbar^2/m_p e^2$, and $\gamma = 3.4 \cdot 10^{11}$ MeV^{-1} cm^{-1}, and also

$$|T|^2 \propto \frac{\sin^2\delta_0}{E_{2p}} \qquad (3)$$

where δ_0 was taken to be the singlet s-wave p-p phase shift, as defined in the expression for the scattering amplitude

$$f(\theta) = f_c(\theta) + 1/(2ik)\, e^{2i\zeta_0}\,(e^{2i\delta_0} - 1) \qquad (4)$$

where $\delta_0 = \mathrm{Arg}\,\Gamma\,(1 + i\eta)$, and finally

$$\rho(E_T) = C(E_T)^{1/2}\,(E_{max} - E_T)^{1/2}$$

where E_{max} is the maximum triton energy in the CM system. Expression (2) corresponds to the treatment of Migdal[5] and expression (3) is due to Watson.[9]

The theoretical CM spectra were converted to the laboratory system using the appropriate jacobian determinant and experimental values for $g(\theta)$. The high energy region of the laboratory spectra is quite insensitive to the angular dependence $g(\theta)$, particularly at small laboratory angles. It is clear from Fig. 2 that expression (2) is most consistent with the data for a value of $a_p = -7.7$ f, which is the scattering length obtained from low energy p-p scattering experiments. For larger values of E_{2p} (smaller E_T), p-t interactions could make expression (1) inaccurate, and therefore it should prove

quite useful to develop an exact calculation of the energy spectrum, free of the usual approximations.[10] On the other hand, the competing p-t final state interaction can be treated in the framework of this simple theory,[11] and it is expected that no significant contribution to the spectrum in the low E_{2p} energy range is due to it.

A triton spectrum from this $He^3(d,t)2p$ reaction obtained with very good statistical accuracy and high energy resolution, could be used to determine independently a value of a_p. A difference from the already established value could provide quantitative information on this question of spectrum distortion, which is of interest with respect to the determination of the n-n scattering length, recently extracted from just such final-state interaction spectra from the D(n,p)2n reaction.[12,13] Thus, we are presently continuing our experiment in order to obtain triton spectra of significantly better statistical accuracy.

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FOOTNOTES AND REFERENCES

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FIGURE CAPTIONS

Fig. 1. A) Typical Identifier spectrum

B) Triton spectrum of the reaction $He^3(d,t)2p$ at $\theta_L = 6.75^0$, $E_d = 24.7$ MeV. Solid dots are the experimental points. Open circles correspond to the calculated spectrum with $a_p = -7.7$ f. The dashed lines are calculated spectra with the indicated values of a_p.

Fig. 2. Triton spectrum of the reaction $He^3(d,t)2p$ at $\theta_L = 8^0$, $E_d = 33.4$ MeV. Solid dots are the experimental points. Open circles correspond to the calculated spectrum with $a_p = -7.7$ f. The dashed lines are calculated spectra with the indicated values of a_p. The high energy side of the spectrum is shown via a magnified energy scale on the upper left; the solid triangles are the experimental points, the solid line is the calculated spectrum with $a_p = -7.7$ f, the dashed line was calculated with $a_p = -9.3$ f, the dash dot line was calculated with $a_p = -6.1$ f, and the dashed double dot line corresponds to expression (3) with $a_p = -7.7$ f.

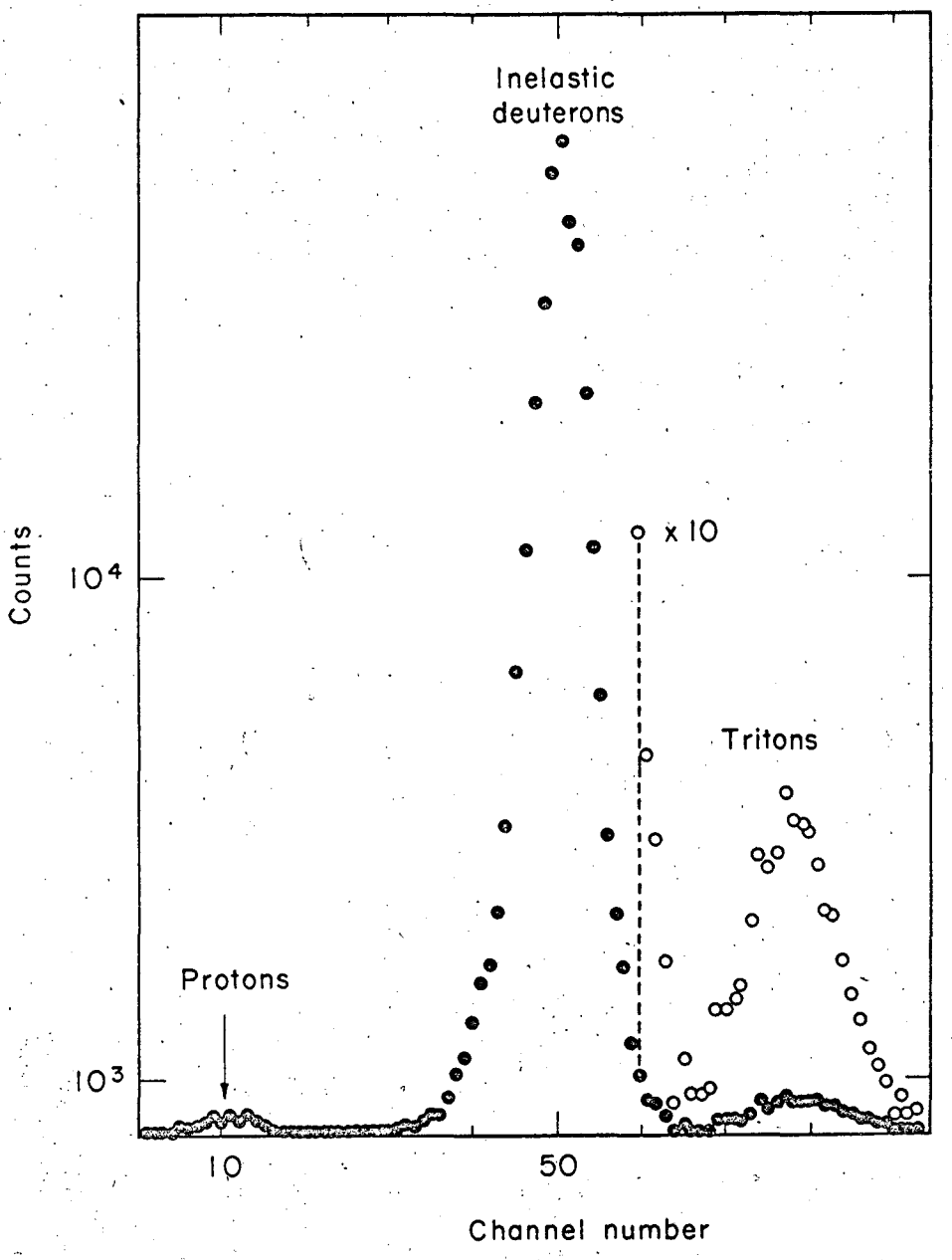
Inelastic
deuterons
x 10
Counts
10^4
Tritons
Protons
10^3
10
50
Channel number
MUB-4259

Fig. 1A.

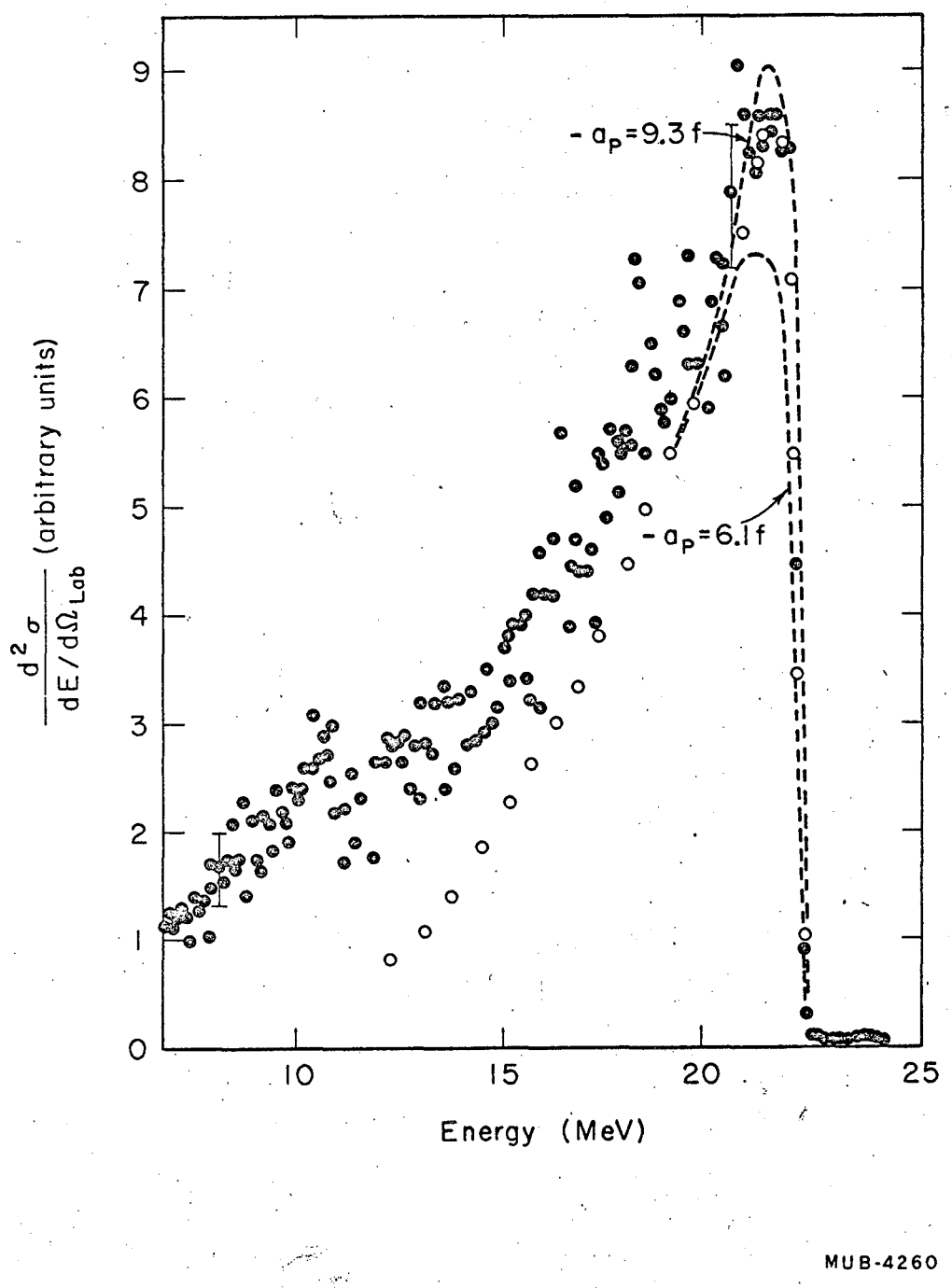
$\frac{d^2\sigma}{dE/d\Omega_{Lab}}$ (arbitrary units)
Energy (MeV)
a_p=9.3 f
a_p=6.1 f
0
1
2
3
4
5
6
7
8
9
10
15
20
25
MUB-4260

Fig. 1B.

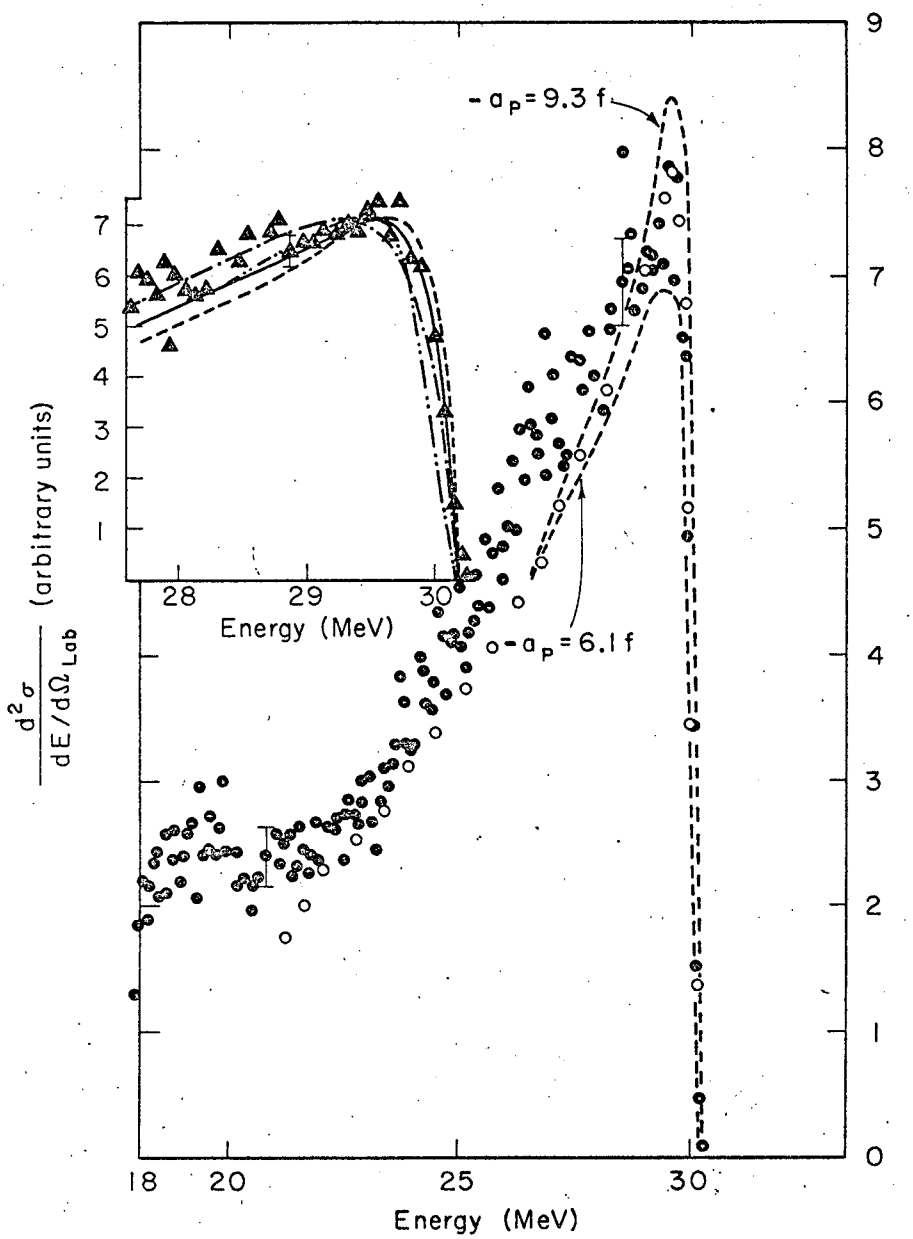
$a_p = 9.3$ f
$a_p = 6.1$ f
$\frac{d^2\sigma}{dE/d\Omega_{Lab}}$ (arbitrary units)
Energy (MeV)
Energy (MeV)
MUB-4261

Fig. 2.