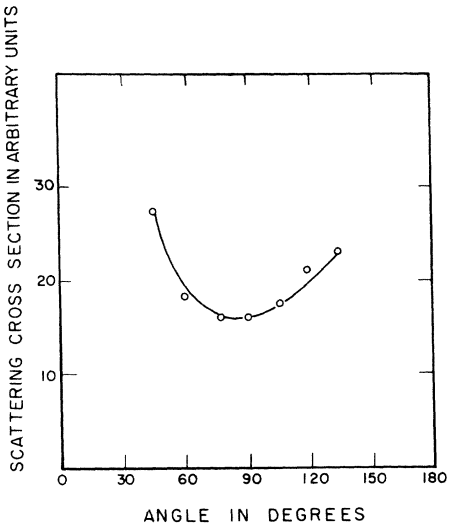

FIG. 2. Total scattering cross section of argon at normal pressure and temperature ($n_0 = 2 \times 10^{19}$ cm^{-3}) for ruby-laser ($\lambda = 6934$ Å) beam polarized normal to scattering plane. Full line calculated from Eqs. (24) and (26); circles are experimental points reported by George et al.[1]

γ depends on the polarization if the laser beam is not symmetric about its axis. Finally, if $\epsilon(60)$ were approximately unity, as is implied in Table I of reference 1, the forward bias of the scattering predicted by Eq. (26) would be much larger than that observed by experiment. It is obvious that more accurate experiments and a theory which takes into account the exact shape of the scattering volume, the intensity distribution in the incident beam, and the solid angle of the scattered beam, are required for explaining the apparent discrepancies between theory and experiment. Such a detailed analysis may profit from the fact that n_0 is constant in space and time for gases which are in thermal equilibrium and free of turbulence. Consequently, scattering associated with the term A_0^2 has exactly the frequency ω of the incident radiation field. On the basis of this property, it can be experimentally distinguished from scattering associated with density fluctuations which is always Doppler shifted in ideal gases.

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[1]T. V. George, L. Slama, M. Yokoyama, and L. Goldstein, Phys. Rev. Letters 11, 403 (1963).

[2]Formula (1) breaks down for small scattering angles since the effective length, $c/\sin\theta$, of the scattering volume is always smaller than an upper limit determined by diaphragms, or the walls of the gas container.

[3]W. K. Panofsky and M. Phillips, Classical Electricity and Magnetism (Addison-Wesley Publishing Company, Inc., Reading, Massachusetts, 1956), 2nd ed., p. 322 ff.

[4]Usually the Thomson factor is given for natural incident light and free electrons with polarizability $e^2\lambda^2/4\pi^2 c_0^2 m_e$ (c_0 = vacuum velocity of light, m_e = electron mass). In this case $T(\theta,\lambda) = (e^4/c^4 m^2) \times (1+\cos^2\theta)/2$.

[5]In plasmas, $\langle n_{\vec{q}} n_{\vec{q}'} \rangle$ depends on the radial distribution function of electrons about electrons.

FINAL-STATE INTERACTIONS IN THE REACTION $He^3(d,t)2p$ AT 24.7 AND 33.4 MeV

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Recent Letters have reported experimental determinations of triton energy spectra from the reaction $He^3(d,t)$ 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 reaction[3,4] $D(p,n)2p$, 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 reaction [$He^3(d,t)2p$].

We report here experimental results along

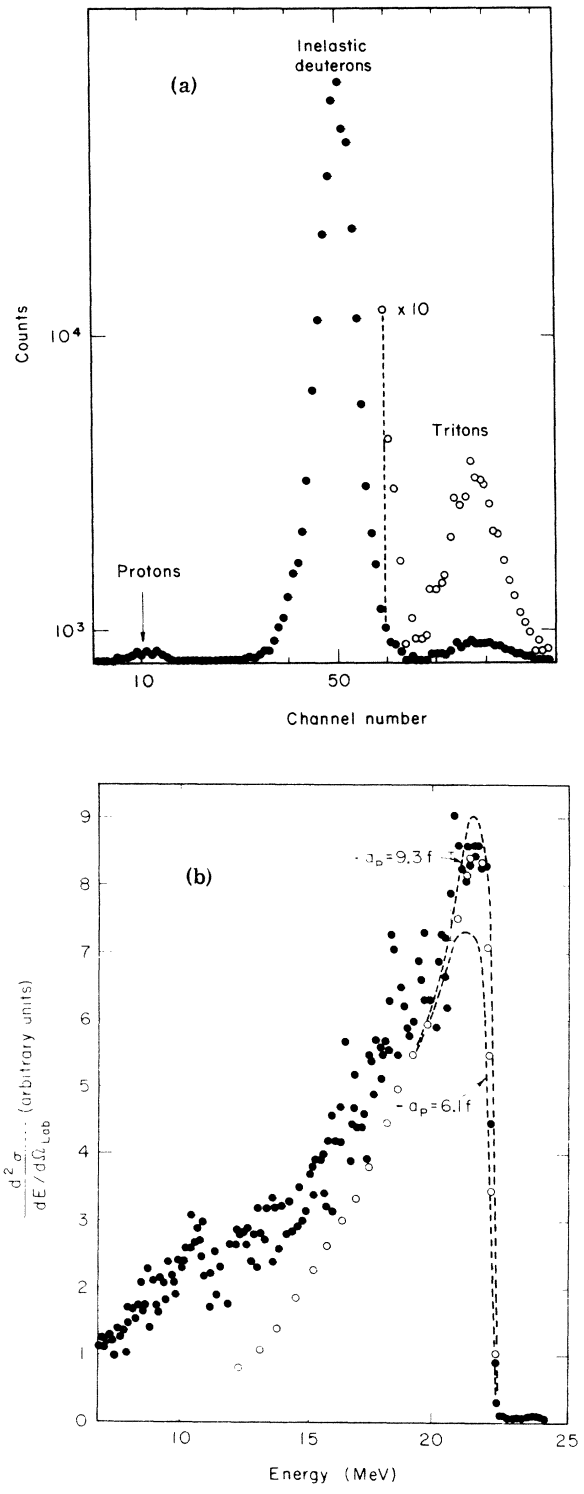

FIG. 1. (a) Typical identifier spectrum. (b) Triton spectrum of the reaction $He^3(d,t)2p$ at $\theta_L = 6.75°$, $E_d = 24.7$ MeV. Solid circles are the experimental points. Open circles correspond to the calculated spectrum with $a_p = -7.7$ F. The dashed lines are calculated spectra with the indicated values of a_p.

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 analyzer whenever a triton identification occurred. The added $(\Delta E + E)$ triton pulse spectrum was then displayed on the analyzer. Also, triton spectra from the reaction $N^{14}(d,t)N^{13}$ were obtained for the purpose of calibration of the energy scale, which we believe to be accurate within 100 keV. Figure 1(a) contains a typical identifier spectrum, and Fig. 1(b) shows a triton spectrum at $\theta_L = 6.75°$ taken at 24.7 MeV. Figure 2 exhibits a spectrum at $\theta_L = 8°$ 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

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

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 $|\varphi_{2p}(q)|$, the $2p$ wave function, where q is the relative momentum.

We have used the following expressions to

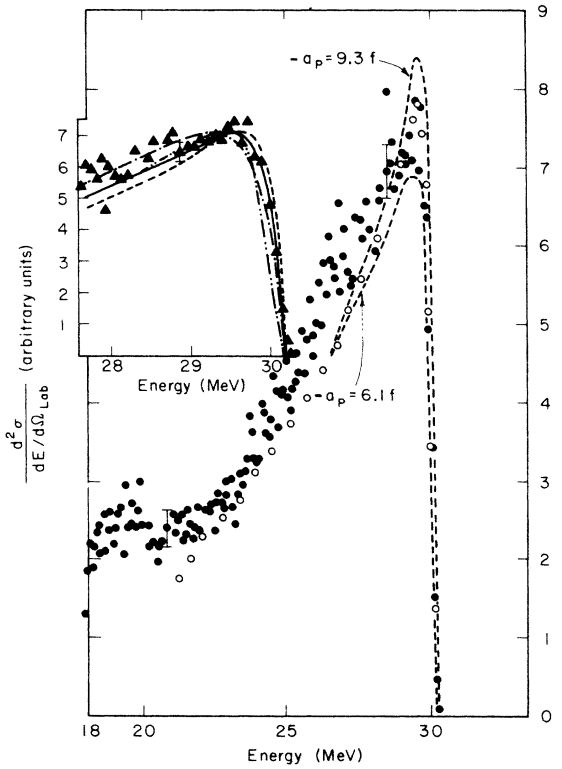

FIG. 2. Triton spectrum of the reaction $He^3(d, t)2p$ at $\theta_L = 8°$, $E_d = 33.4$ MeV. Solid circles are the experimental points. Open circles correspond to the calculated spectrum with $a_p = -7.7$ F. The dashed lines are calculated spectra with the indicated values of a_p. The high-energy side 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.

fit our data:

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

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 $h(\eta) = \mathrm{Re}[\Gamma'(-i\eta)/\Gamma(-i\eta)] - \ln\eta$, $R = \hbar^2/m_p e^2$, and $\gamma = 3.4\times10^{11}$ MeV^{-1} cm^{-1}. Also,

$$|T|^2 \propto \sin^2\delta_0/E_{2p}, \quad (3)$$

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

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

where $\delta_0 = \arg\Gamma(1+i\eta)$. 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 c.m. system. Expression (2) corresponds to the treatment of Migdal,[5] and expression (3) is due to Watson.[9]

The theoretical c.m. 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 reaction [$He^3(d, t)2p$] 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 reaction $D(n,p)2n$.[12,13] Thus, we are presently continuing our experiment in order to obtain triton spectra of significantly better statistical accuracy.

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EVIDENCE FOR A SINGLE DOMINANT STATE FOR THE $E1$ GIANT RESONANCE*

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The success of the particle-hole model[1-3] in explaining the gross properties of the giant-dipole resonance has stimulated some extensive calculations[4-7] which attempt to describe some of the more detailed properties of the giant resonance in closed-shell nuclei. These calculations have shown that ordinarily several particle-hole states are major contributors to a given giant-dipole resonance. While the calculated energies of these states are not all identical, they do tend to cluster in the desired region—a typical calculation gives several states within a region of a few MeV. As the calculations have been refined, so has the energy resolution of the experiments been improved. The improved experiments have indeed established structure within the giant resonance; in many cases there are several prominent peaks in a region of a few MeV. Thus, it has been natural to identify the observed structure with the various predicted particle-hole states,[8] especially since considerable leeway is possible in making such identifications since the calculations predict the positions of the states only within about 1 MeV. It is the purpose of this note to report that more detailed information makes such identification untenable.

In the program of studying the giant-dipole resonance through the (p,γ) reaction with protons from the ANL tandem van de Graaff, the nuclei C^{12}, Ne^{20}, and Si^{28} have been investigated. In each case the giant resonances involving transitions to the ground state (γ_0) and first excited state (γ_1) of the nucleus have been studied. The various experiments are discussed in detail elsewhere,[9-11] and the relevant results are summarized in Table I. The result that is most important to the present discussion is that throughout each giant resonance the gamma-ray angular distribution varies little with energy. Specifically, it is found that to within the experimental accuracy of about ± 0.1 the angular distribution coefficients usually remain close to their average values. Excursions in magnitude up to about 0.3 occasionally occur in a_2, the coefficient of P_2; and slow trends of up to about 0.03/MeV are sometimes present in a_1 and a_2. Spin and parity considerations alone would permit a_2 to vary from about $+1$ to -1 for pure $E1$ radiation, the exact limits depending on the quantum numbers involved in each giant resonance. (The odd terms in the angular distribution can be attributed[9,11] to interference with weak positive-parity radiation which contributes but incoherently to a_2.) Thus, the angular distributions appear to be much more nearly constant than might be expected from the complexity of the yield curves. A similar result has been obtained in other laboratories[12,13] for $N^{15}(p,\gamma_0)O^{16}$ and $P^{31}(p,\gamma_0)S^{32}$. This result implies that whatever the structure of a given giant resonance (and Table I shows that different giant resonances