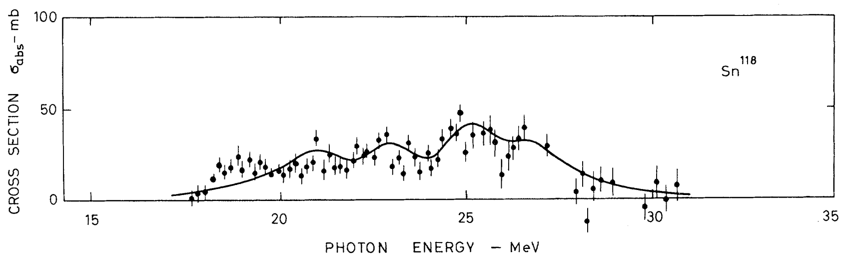

FIG. 2. The experimental excess cross section (see Ref. 6) over the theoretical giant dipole tail compared with the theoretical quadrupole absorption cross section (full curve).

possibly be due to the vibrational giant dipole satellites predicted at about these energies (see the lower part of Fig. 1). In fact, it has been shown[7] that the escape widths of the giant dipole satellites can vary quite appreciably. Nevertheless, more experimental evidence is necessary to confirm the interpretation of this structure as quadrupole giant resonances. The electron excitation of these resonances in medium heavy nuclei should be especially valuable.[8]

Table I. The various parameters for the Sn isotopes. $\hbar\Omega_1$ and $\hbar\Omega_2$ denote the unperturbed giant dipole and giant quadrupole energies, respectively. $\hbar\omega$ is the energy of the first 2^+ surface phonon, β_0 is the mean deformation, and Γ_D and Γ_Q are the assumed widths of the giant dipole and giant quadrupole resonances, respectively. α is the parameter for the effective mass.

	Sn^{118}	
$\hbar\Omega_1 = 15.6$ MeV		$\Gamma_D = 4.8$ MeV
$\hbar\omega = 1.230$ MeV	$\alpha = 0.2$	$\Gamma_Q = 2$ MeV
$\beta_0 = 0.116$		
$\hbar\Omega_2 = 25.0$ MeV		
	Sn^{124}	
$\hbar\Omega_1 = 15.2$ MeV		$\Gamma_D = 4.8$ MeV
$\hbar\omega = 1.131$ MeV	$\alpha = 0.2$	$\Gamma_Q = 2$ MeV
$\beta_0 = 0.108$		
$\hbar\Omega_2 = 24.4$ MeV		

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SINGLET DEUTERON EMISSION IN A (He^3, $\tilde{d}$) REACTION DESCRIBED BY DISTORTED-WAVE BORN APPROXIMATION

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Emission of singlet deuterons was observed in the reaction $B^{10}(He^3, \tilde{d})C^{11}$ by studying neutron-proton correlations. The resulting angular distributions are very similar to those of triplet deuterons and can be described in distorted-wave Born approximation assuming the $\tilde{d}$ to behave like a single particle.

The mechanism of a nuclear reaction yielding three particles may be dominated by final-state interaction between two of them, which in the case of the neutron-proton system leads to an enhancement of the cross section at small relative energies, related to the existence of a bound state (−2.23 MeV, triplet, $S=1$, $T=0$) and an antibound state (−0.06, singlet, $S=0$, $T=1$, sometimes erroneously referred to as a resonant state). The singlet interaction being dominant at vanishing energies, for such a correlated nucleon pair the term singlet deuteron ($\bar{d}$) was coined.[1] Various authors discussed the use of such a "particle" as a spectroscopic tool.[2] A prerequisite for this is the quantitative understanding of reactions yielding such pairs.

Experimental evidence that such a process occurs at all has been rather scarce, however. Only Cohen et al.[1] observed (p,pn) reactions on various nuclei which they interpreted as $(p,\bar{d})$ reactions. In this paper we present evidence for a $(He^3,\bar{d})$ reaction leading to different states of the final nucleus and compare it with the parallel (He^3,d) reaction. It is shown that both reactions can be described surprisingly well in a consistent manner by a simple distorted-wave Born approximation (DWBA) calculation, assuming both neutron-proton systems to behave as individual entities within the optical potentials of the nucleus, differing only in spin and isospin in the two cases.

We irradiated a B^{10} target (enrichment 96%) with 8-, 10-, and 11-MeV He^3 particles and observed neutron-proton coincidences, detecting the protons by a solid-state detector telescope and neutrons by a liquid scintillator placed 30 cm behind it. In a two-dimensional array we registered the proton energy and the neutron time of flight, using the telescope pulse as a start signal.[3] Coincident events were located on three kinematic plots, corresponding to transitions to states in C^{11} at 0.00, 4.31, and 6.49 MeV.[4] Apart from a few events corresponding to sequential reactions $B^{10}(He^3,n)N^{12}(p)C^{11}$ and $B^{10}(He^3,p)C^{12}(n)C^{11}$,[5] on each plot we observed a broad continuum peaked at zero relative energy. Figure 1 gives examples obtained with both detectors placed at 15° or 12.5° to the incoming He^3 beam at different incident energies. Similar spectra were obtained at other common angles. The continuum

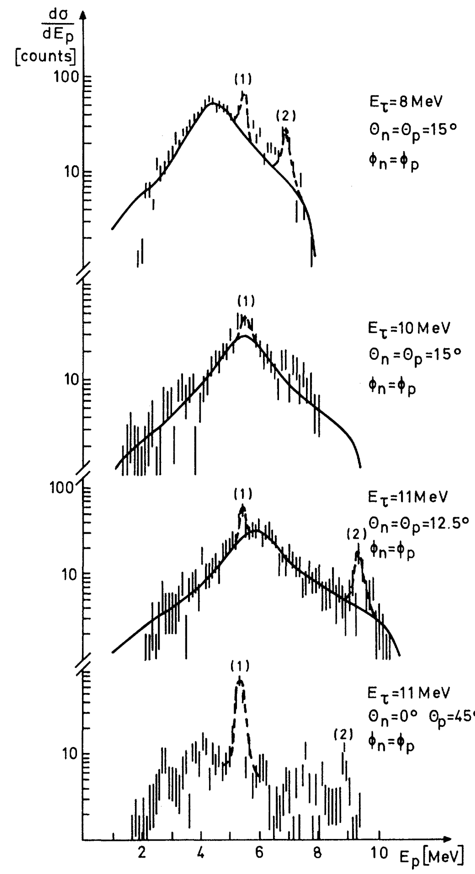

FIG. 1. Neutron-proton coincidence spectrum from $B^{10}(\tau,np)C^{11}$. Solid angle spanned by neutron and proton detector: 2.6×10^{-2} and 8.7×10^{-4} sr, respectively. Solid line: result of final-state interaction in effective-range approximation. Incoherent superposition of singlet plus triplet scattering in the statistical ratio 1:3. At small relative energies singlet scattering is predominant. The detection efficiency of the neutron detector (cf. Ref. 3) has been taken into account. Note two sequential reaction lines.

decreased with increasing relative angle between the neutron and proton detectors (bottom). The solid lines represent the function

$$W^2\rho=\left(\frac{1}{4}\,\frac{a_s{}^2}{k^2a_s{}^2+(1-\tfrac{1}{2}k^2a_sr_s)^2}+\frac{3}{4}\,\frac{a_t}{k^2a_t{}^2+(1-\tfrac{1}{2}k^2a_tr_t)}\right)\rho(E_p),$$

where k = relative momentum; a = scattering length; r = effective range; s = singlet; t = triplet, ρ = phase-space factor; E_p = proton energy. This is expected to govern the final state interaction in the effective range approximation[6] and was transformed to a function of the proton energy taking into account also the neutron detection efficiency. The excellent agreement shows that the description in terms of final-state interaction is appropriate. We transformed these spectra into functions of the relative energy E_{np} and then used the peak height at $E_{np}=0$ as representative for singlet deuteron emission, this quantity being the most reliable one. We then plotted this value as a function of the common neutron- and proton-emission angle and for three final states in C^{11} [Fig. 2(a)]. Also shown is the simultaneously measured distribution of bound triplet deuterons [Fig. 2(b)]. The cross-section scale for the latter was obtained by conventional means. From this, the scale for the other reaction was obtained by using the fact that the same detection efficiency and solid angle applied for the protons as for the deuterons and taking the solid angle of the neutron detector and its detection efficiency into account. The general similarity of Figs. 2(a) and 2(b) suggests that a similar reaction mechanism is effective for singlet- and triplet-deuteron emission. A consistent description in DWBA was tried in the following way.

For the triplet deuteron emission the (τ, d) cross section is[7]

$$\frac{d\sigma}{d\Omega}d(\theta_d)=\frac{2\pi}{\hbar^2}\frac{\mu_\tau}{k_\tau}W_d^2|M_d(\vec{k}_d)|^2\rho(E_d)=N_d\sigma^{\mathrm{DW}}(\vec{k}_d)G.$$

k_d, k_τ are the momenta of deuteron and He^3, respectively; ρ is the final-state density; W_d^2 describes the decomposability of He^3 into d and p,[10] and $|M_d|^2$ the reaction proper. Apart from a transition strength G related to the overlap of initial and final nuclear states and a constant $N_d \sim W_d^2$ the cross section is calculated by a DWBA code JULIE[7] as σ^{DW}.

In an analogous way we write for the emission of a neutron-proton pair with relative energy $E_{np}=0$ at common angle $\theta_n=\theta_p$, with phase space factor $\rho(E_{np}=0)$,

$$\frac{d^3\sigma}{d\Omega_n d\Omega_p dE_{np}(E_{np}=0)}(\theta_n=\theta_p)=\frac{2\pi}{\hbar^2}\frac{\mu_\tau}{k_\tau}W_{\bar{d}}^2(k_{np}=0)|M_{\bar{d}}(\vec{k}_{\bar{d}}=2\vec{k}_n=2\vec{k}_p)|^2\rho(E_{np}=0).$$

We now make the assumption that the two M functions are essentially equal, thus enabling the description of the singlet deuteron emission by the standard σ^{DW}:

$$|M_{\bar{d}}(\vec{k}_{\bar{d}})|^2=C_1|M_d(\vec{k}_d)|^2\equiv C_1\rho^{-1}(E_d)[|M_d(\vec{k}_d)|^2\rho(E_d)]=C_1\rho^{-1}(E_d)\sigma'^{\mathrm{DW}}(\vec{k}_d)G.$$

The prime denotes replacement in the DW code of the Q value of the (τ, d) reaction by $Q-2.23$ MeV referring to the $(\tau, \bar{d})$ reaction. Hence,

$$\frac{d^3\sigma}{d\Omega_n d\Omega_p dE_{np}(E_{np}=0)}$$
$$=C_2W^2(k_{np}=0)\rho(E_{np}=0)\rho^{-1}(E_d)\sigma'^{\mathrm{DW}}(k_d)G.$$

Inserting the expressions for the ρ's, we obtain

$$\frac{d^3\sigma}{d\Omega_n d\Omega_p dE_{np}(E_{np}=0)}=C_3E_d^{1/2}\sigma'^{\mathrm{DW}}(k_d)G.$$

In this expression the quantity C_3 was adjusted to match the measured ground-state transition at the maximum of the angular distribution [Fig.

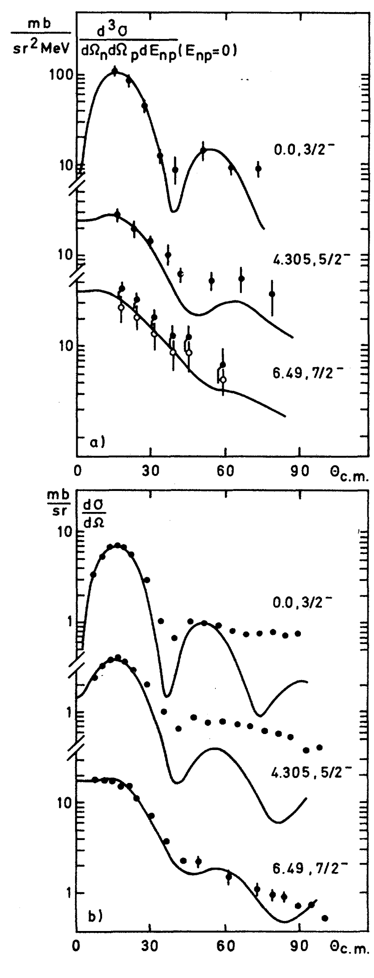

FIG. 2. Angular distribution of (a) singlet deuterons and (b) triplet deuterons. Solid lines: DWBA calculations, with parameters (notation of Ref. 7; energies in MeV, lengths in fm) as follows: For $B^{10}+He^3$, $V=140$, $V_{so}=6$, $W=30$, $W'=0$, $r_0=1.20$, $a=0.83$, $r_0'=2.15$, $a'=0.3$ (Ref. 8). For $C^{11}+d$ ($\bar{d}$): $V=118$, $V_{so}=5.8$, $W=4.82$, $W'=0$, $r_0=0.895$, $a=0.902$, $r_0'=1.62$, $a'=0.775$ (Ref. 9); bound state, $r_0=1.25$, $a=0.65$, $\lambda=25$. The fits are normalized at the peak of the respective g.s. transition. The ordinate scales are consistent for both figures within 20%. Error of the absolute calibration: 15%. Part of the apparent cross section for $B^{10}(\tau, d)C^{11}(6.49)$ might be due to $C^{12}(\tau, \bar{d})N^{13}(0.00)$. The well resolved respective (τ, d) reactions allowed a correction, yielding the open circles for the former transition.

2(a)]. No further adjustment was made; the relative transition strengths G for the excited C^{11} states were taken from the respective (τ, d) reaction. The shape and relative strengths of the different transitions are nicely reproduced; the difference in relative intensity for the different states in the $(\tau, \tilde{d})$ and (τ, d) reactions thus are seen to be purely kinematic in origin, as less kinetic energy is available in the $\tilde{d}$ than in the d case. Thus it may be concluded that the $(T=1, S=0)$ deuteron emission is a real process that can safely be described by DWBA with respect to shape and relative strengths and thus may be used as a new spectroscopic tool. On the other hand it is seen that for a comparison of reactions yielding d and $\tilde{d}$, as in Ref. 1, a DWBA treatment is essential. To reproduce the measured cross section absolutely a theory on the "normalization" of the DWBA cross section is required that incorporates the decomposability of He^3 into p and $\tilde{d}$, analogous to the works of Bassel,[10] Rook,[11] and Lim[12] for the (He^3, d) case. It is hoped that such a theory (which is beyond the scope of this paper) will show quantitative consistency of the DWBA treatment also for emission of unstable particles.

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PION-EXCHANGE DOMINANCE IN THE REACTION $pp \to n\Delta^{++}(1236)$ AT HIGH ENERGIES*

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The charge-exchange reaction $pp \to n\Delta^{++}(1236)$ has been systematically analyzed up to 24.2 GeV/c to test the concept of dominance in the t channel by high-lying Regge trajectories at very high energies. The results provide clear evidence for no more than pion exchange up to the highest momentum studied.

For a reaction in which the exchange of several Regge poles is allowed, it is expected that the high-lying trajectories will dominate at very high energies. Specifically, for a reaction which is mediated by the exchange of a single Regge pole, the differential cross section may be written as

$$d\sigma/dt \sim F(t) P_L^{2\alpha(t)-2}, \quad (1)$$

where P_L is the incident beam momentum, $\alpha(t)$ is the trajectory, and $F(t)$ contains the propagator and residue functions. The differential cross section at low t then varies as $P_L^{2\alpha(0)-2}$. Therefore, the greater the value of $\alpha(0)$, the slower will the differential cross section fall with increasing incident momentum. A sensitive test of the notion involves the examination of charge-exchange reactions for which the exchanges of the π and ρ (and heavier charged trajectories) are allowed. If a reaction is dominated by pion exchange, the cross section will be expected to fall as P_L^{-2}, whereas a less rapidly falling trend in the form of P_L^{-1} will be indicative of a ρ exchange.

In this paper, we present the results of such a test using the reaction $pp \to n\Delta^{++}(1236)$ from 13.0 and 24.2 GeV/c. To our knowledge there has been no systematic study of a single quasi-two-body reaction covering such a wide range of momenta above 10 GeV/c. Measurements of the reaction $pp \to p\Delta^+$ have been performed up to 15 GeV/c using counter, spark-chamber methods incorporated into a one-arm proton spectrometer.[1] In these experiments, the outgoing detected