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THE ELECTRODISINTEGRATION OF POLARIZED DEUTERON AND THE FINAL STATE INTERACTION

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Introduction

The mechanism of electrodisintegration of polarized deuterons is very interesting in view of the possibility to extend our knowledges about both the usual nucleon structure and exotic components (multiquarks, Δ-isobars etc.) of a deuteron. Moreover the polarization experiments seem to be sensitive to any exotics as compared with unpolarization ones. Notice that very often some exotic components are investigated in the simple plane wave approximation with complete neglect of secondary nuclear effects. It is evident that this kind of approaches may lead to incorrect consideration of the role of the exotics in the nuclear processes. The FSI is the first evident effect which must be taken into account. Below we investigate the effects of final state interaction in electrodisintegration of a polarized deuteron in exclusive and inclusive cases.

The exclusive $\vec{d}(e, e'n)p$ - reaction

The cross section of the exclusive $ed \to e'np$ - reaction where the final electron e' and the neutron are detected in a coincidence has the form [1] :

$$\sigma_3 \equiv \frac{d^3\sigma}{d\varepsilon_f d\Omega_f \Omega_n} = \sum_{M_i} \sigma_3(M_i), \tag{1}$$

$$\sigma_3(M_i) = F W_{M_i}, \tag{2}$$

$$W_{M_i} = \frac{1}{4\pi(2J_i+1)} \sum_{M_f} \mid J_{M_i M_f} \mid^2, \tag{3}$$

$$J_{M_i M_f} \equiv \int d\mathbf{r} e^{i\mathbf{q}\mathbf{r}} \langle f \mid \rho(r) \mid i \rangle, \tag{4}$$

where $q_\mu = (\mathbf{q}, \omega)$ is the four-momentum transfer to the deuteron, $\mathbf{q} = \mathbf{k}_i - \mathbf{k}_f$, $\omega = \varepsilon_i - \varepsilon_f$; $k_{i(f)} = (\mathbf{k}_{i(f)}, \varepsilon_{i(f)})$ is the four-momentum of the electron in the initial (final) state; $k_p = (\mathbf{k}_{i(f)}, \varepsilon_{i(f)})$ are the momentum carried by on proton and neutron; M_i, M_f are the total momentum projections of the nucleon system in initial and final states on the axis of quantization chosen in the direction of the primary electron beam; F is the kinematical factor (see [1]).

The tensor analysing power is usually defined in the form:

$$T_{20}^{excl} = \frac{1}{\sqrt{2}} \frac{\sigma_3(M_i = +1) + \sigma_3(M_i = -1) - 2\sigma_3(M_i = 0)}{\sigma_3}. \tag{5}$$

If np-interaction in the final state is neglected (the plane wave approximation - PW), the form of longitudinal component of current is [1]:

$$J^{PW}_{M_iM_f}(q,\mathbf{k}_n) = 4\pi f(q)\sum_{L=0,2} i^L(LM_i - M_f 1M_f \mid 1M_i) \times\rho_L(k_n)Y_{LM_i-M_f}(\hat{\mathbf{k}}_n) \qquad (6)$$

where f(q) is the form factor of nucleon, ρ_0, ρ_2 are s- and d-waves of the deuteron. Then T_{20} is determined only by relative motion of the nucleons. If the neutron is detected at the zero angle from the initial beam direction $\theta_n = (\widehat{\mathbf{k}_n,\mathbf{k}_i}) = 0$, then T_{20} becomes:

$$(T^{excl}_{20})^{PW} = \frac{1}{\sqrt{2}}\rho_2(k_n)\frac{2\sqrt{2}\rho_0(k_n)+\rho_2(k_n)}{\rho_0^2(k_n)+\rho_2^2(k_n)}. \qquad (7)$$

The same expression for the tensor analysing power of the reactions with a polarized deuteron can be obtained under the following assumptions: the one-pole approximation for the mechanism of reactions and the plane wave approximation in the final state. If one goes away from the plane wave approximation then the expression for T_{20} becomes more complicated and it is impossible to get a simple analytic formula in terms of s- and d-waves of the deuteron.

In fact, the final state of np -system with taking account of FSI has the form:

$$\mid f\rangle = e^{i\mathbf{KR}}\Psi^{M_f}_{\mathbf{k}_{np}}(\mathbf{r}) \qquad (8)$$

where $\mathbf{K} = \mathbf{k}_p + \mathbf{k}_n, \mathbf{k}_{np} = \mathbf{k}_p + \mathbf{k}_n$. The quantity $\Psi^{M_f}_{\mathbf{k}_{np}}(\mathbf{r})$ is the wave function of relative motion of nucleons and it is represented as a sum of the plane wave when there is no FSI plus the "distored" wave $[\mid f\rangle = \mid PW\rangle + \mid DW\rangle]$:

$$\Psi^{M_f}_{\mathbf{k}_{np}}(\mathbf{r}) = e^{i\mathbf{k}_{np}\mathbf{r}}\chi_{1M_f} + 4\pi\sum_{JLm} i^L(Lm1M_f \mid Jm+M_f) \times U^{M_f}_{JL}(k_{np},r)Y^*_{Lm}(\hat{\mathbf{k}}_n). \qquad (9)$$

where $J = L, L\pm 1$ is the total momentum of nucleon system.

Now the expression for the current is:

$$J_{M_iM_f} = J^{PW}_{M_iM_f} + J^{DW}_{M_iM_f}, \qquad (10)$$

where $J^{PW}_{M_iM_f}$ is defined by eq.(6) and

$$J^{DW}_{M_iM_f}(\mathbf{q},\mathbf{k}_{np}) = (4\pi)^2 f(q)\sum_{LJl\ell} i^{l-L}\left[\frac{(2l+1)(2\ell+1)}{4\pi(2L+1)}\right]^{\frac{1}{2}} \times R^{M_f}_{JLl\ell}(k_{np},q)\sum_m Y^*_{lm}(\hat{\mathbf{q}})Y_{Lm+M_i-M_f}(\hat{\mathbf{k}}_{np})B^{M_iM_fm}_{JLl\ell}, \qquad (11)$$

$$B^{M_iM_fm}_{JLl\ell} \equiv (Lm+M_i-M_f1M_f \mid Jm+M_i)(l0\ell 0 \mid L0) \times\sum_\mu (Lm+M_i-\mu 1\mu \mid Jm+M_i)(\ell M_i-\mu 1\mu \mid 1M_i) \times(lm1M_i-\mu \mid Lm+.M_i-\mu),$$

$$R^{M_f}_{JLl\ell} = \int dr\ r\ U^{M_f\,*}_{JL}(k_{np},r)\ j_l(qr/2)\ u_\ell(r). \qquad (12)$$

Using eq.(10) the cross section (2) has the form:

$$\sigma^{DW}_3(M_i) = F\frac{1}{4\pi(2J_i+1)}\sum_{M_f}[\mid J^{PW}_{M_iM_f}\mid^2 + \mid J^{DW}_{M_iM_f}\mid^2 + 2(J^{PW}_{M_iM_f}J^{DW\,*}_{M_iM_f})\ ]. \qquad (13)$$

In this case the expression for T_{20} doesn't transform into eq.(7) and it should be calculated as

$$(T^{excl}_{20})^{DW} = 1 - 3\sigma^{DW}_3(M_i=0)/\sum_{M_i}\sigma^{DW}_3(M_i). \qquad (14)$$

In our analysis the wave function of np-system in a continuous spectrum has been obtained by numerical solving the Shrӧedinger equation with a realistic Paris potential [2].

Figure 1 shows the different behaviour of the cross sections σ^{PW}_3 and σ^{DW}_3 with $M_i = 0$ and summarized on $M_i = 0,\pm 1$. The calculations are

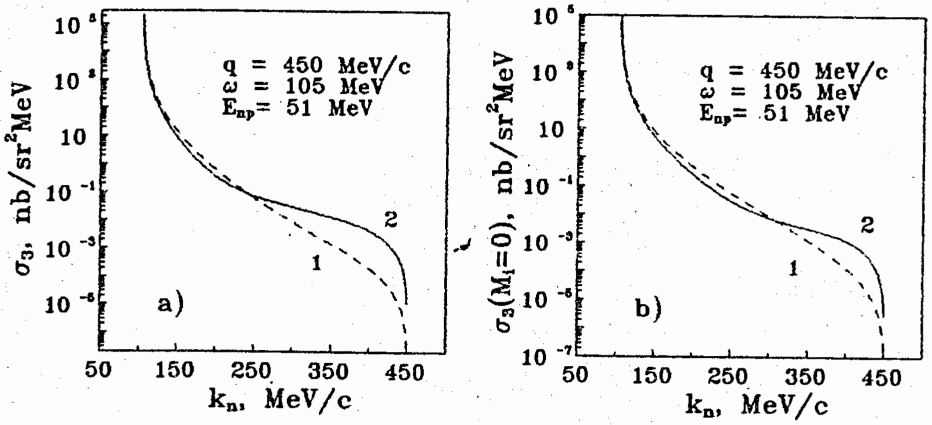


Fig.1 *The exclusive cross section of electrodisintegration of a deuteron: a) - summarized on $M_i = 0, \pm 1$; b) - with $M_i = 0$. Curves: 1 - PW; 2 - PW+FSI.*

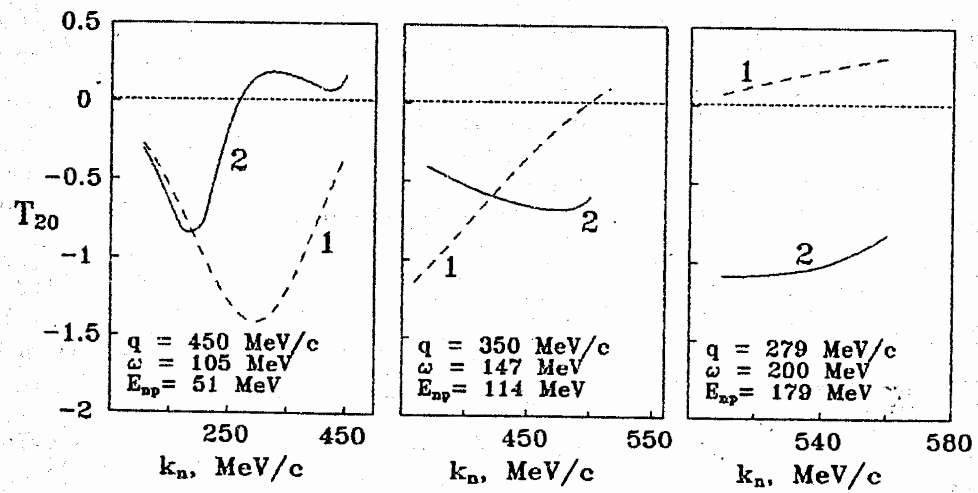
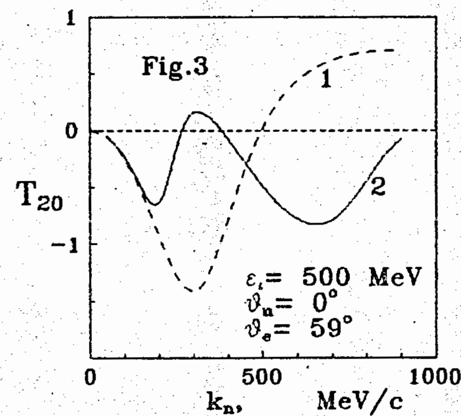


Fig.2 *The tensor analysing power T_{20} in the exclusive reactions of electrodisintegration of a polarized deuteron in the kinematics with fixed E_{np} and $\theta_n = 0^o$. Curves: 1 - PW; 2 - PW+FSI.*



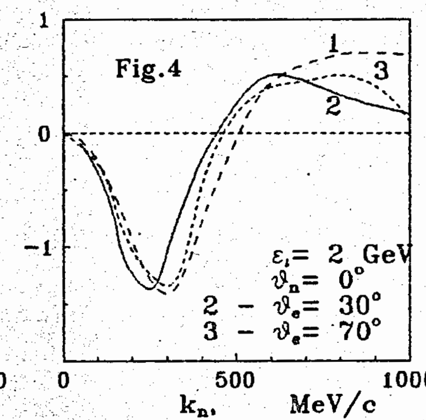


Fig.3 *The notation is the same as in fig.2, but fixed ε_i and $\theta_n = 0^o$.*
Fig.4 *The notations is the same as in fig.3, but with other ε_i.*

performed in kinematical conditions of experiments at Saclay [3] with a fixed momentum transfer ($q_\mu = (\mathbf{q}, \omega)$).

The presented differences in the cross sections lead to the qualitatively different behaviour of T_{20}^{PW} and T_{20}^{DW}. In fact, one can see from fig.2 that T_{20}^{DW} changes sign whereas T_{20}^{PW} remains negative.

The results of calculations in more realistic conditions are presented in fig.3. In this case the angle of the neutron momentum direction $(\widehat{\mathbf{k}_n, \mathbf{k}_i}) = \theta_n$ and scattering angle θ_e are fixed and only $\mid \mathbf{k}_n \mid$, $\mid \mathbf{k}_f \mid$ are changed. We choose $\varepsilon_i = 500MeV$, $\theta_e = 59^o$ and $\theta_n = 0$.

One can see the significant difference of the T_{20} behaviour with and without taking account of FSI. The "contribution" of FSI increases with decreasing energy of the relative np - motion (E_{np}). In this example E_{np} changes in the low energy region. So the effect of FSI is large.

Figure 4 shows the result of calculation in "experimental conditions" of *CEBAF*. One can see that in principle it is possible to find the experimental conditions so that the contribution of FSI will be negligible and all "peculiarities" of T_{20} will arise only from the deuteron structure effects.

The inclusive $\vec{d}(e,n)e'p$ - reaction

The tensor analysing power T_{20} which is also called the quadropolarization sensibility, is defined in analogy with eq. (5) as:

$$T_{20}^{incl} = \frac{1}{\sqrt{2}}\frac{\sigma_2(M_i=+1)+\sigma_2(M_i=-1)-2\sigma_2(M_i=0)}{\sigma_2}, \qquad (15)$$

where the inclusive cross section is obtained by integration:

$$\sigma_2(M_i) \equiv \frac{d^2\sigma(M_i)}{dE_n d\Omega_n} = \int \sigma_3(M_i) d\Omega_e = \qquad (16)$$

$$= \int_{(\theta_e)_{min}}^{(\theta_e)_{max}} W_{M_i}(\mathbf{q},\mathbf{k}_p,\mathbf{k}_n) f(\mathbf{k}_i,\mathbf{k}_f,k_p,k_n)\, d\vartheta_e,$$

where $f(\mathbf{k}_i,\mathbf{k}_f,k_p,k_n)$ is the kinematical factor:

$$f(\mathbf{k}_i,\mathbf{k}_f,k_p,k_n) = \frac{4\alpha^2}{\pi}\frac{m_p\, m_n\, k_n\, k^2\ \sin\vartheta_e}{\mid k_i+m_d-E_n+(k_n-k_i)\cos\vartheta_e \mid} \times \frac{1+\sin^2(\frac{\vartheta_e}{2})}{(k_i^2+k^2-2k_ik\cos\vartheta_e)^2},$$

$$k \equiv \frac{2k_i(m_d-E_n+k_n\cos\vartheta_e)+(m_d-E_n)^2-m_p^2-k_n^2}{2(k_i+m_d-E_n+(k_n-k_i)\cos\vartheta_e)},$$

and W_{M_i} is defined by eq.(3).

If the neutron-spectator is emitted at an angle 0^o ($\vartheta_n = 0$), the factorization takes place in the plane wave approximation:

$$\sigma_2^{PW}(M_i) = \mathcal{F}\sum_{M_f} \mid I_{M_iM_f}(k_n) \mid^2, \qquad (17)$$

$$I_{M_iM_f}(k_n) = \frac{1}{4\pi} e^{q^2/\Omega} J^{PW}_{M_iM_f},$$

where $\mathcal{F}$ is a function independent of $\mathbf{k}_n$ and the spin variable (here the explicit expression of $\mathcal{F}$ is not important).

As follows from eq.(17), in the PW eq.(15) transforms into eq. (7) which is usually used in interpretation of experimental data. If FSI is taken into account, we have to use the general eq. (15).

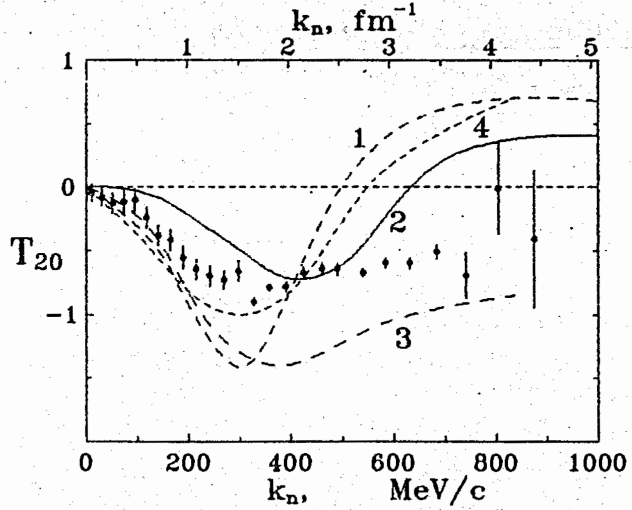


Fig.5 *Curves 1, 2 - the tensor analysing power T_{20} in the inclusive reactions of electrodisintegration of a polarized deuteron: 1 - PW, 2 - PW+FSI. Curves 3, 4 - T_{20} in the reaction of fragmentation $\vec{d}C^{12} \to p(0^o)X$ [5], [6] (see text). The experimental data are from [4].*

Figure 5 shows the difference between predictions of $(T_{20}^{incl})^{PW}$ (eq.(7)) - curve 1, and $(T_{20}^{incl})^{DW}$ (eq.(15)) - curve 2.

The comparison with other reactions

It is useful to compare our calculations for the electrodisintegration of a polarized deuterons with the experimental data and the theoretical predictions for other reactions. So, fig.5 shows the experimental points corresponding to fragmentation of the polarized deuteron in $\vec{d}p$ - reaction [4]. Curve 3 is to the calculation with taking account of the relativistic effects [5] and curve 4 - the relativistic effects in the deuteron plus the nucleon-deuteron interaction calculated in the framework of the light cone dynamics [6]. We have used this reaction because the theoretical predictions for T_{20} for the fragmentation and electrodisintegration in the one-pole approximation coincide. One can see that the FSI "changes" the PW predictions by the same order of magnitude as the contribution of the exotic mechanism and qualitatively agrees with the experimental data.

It is interesting the comparison our results with the calculations by Karmanov [8] of T_{20} in the reaction $pd \to p(180^o)d$. In the amplitude of reaction he took account of a one-nucleon exchange and an influence of "background" (rescattering of nucleons, a creation of pions, Δ-isobars, etc.). Figure 6 shows the result from [8] and the fragment of our cal-

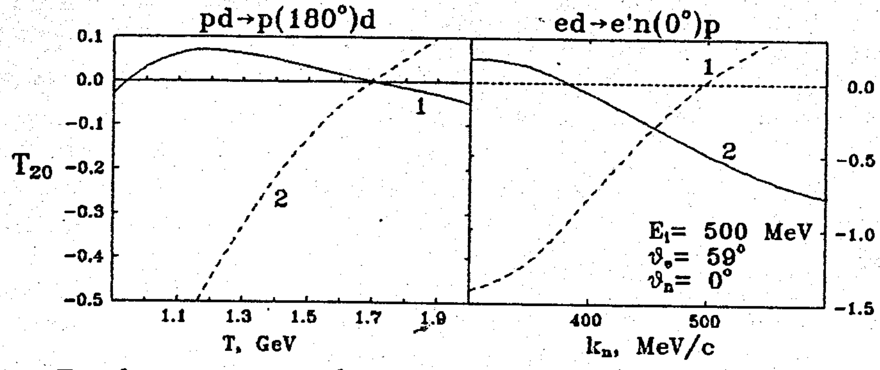


Fig.6 *For the notation see the text*

culations. One can see that making more precise the mechanism of reactions changes the behaviour of T_{20} in some kinematical regions.

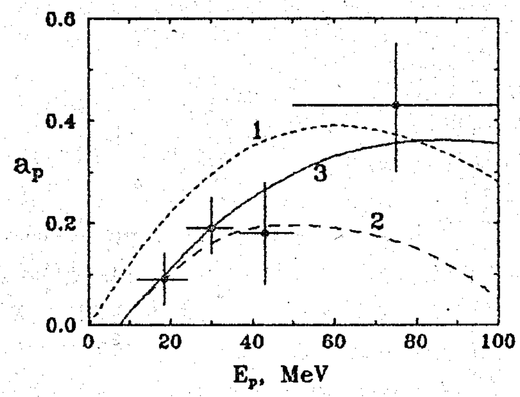


Fig.7 *For the notation see the text*

An other example is the analysis of the first data on inelastic scattering of a polarized deuteron[9,10] (fig.7). The theoretical calculations of asymmetry a_p using the non-relativistic impulse approximation don't describe the experimental data (curve 1). The relativistic impulse approximation [11] allows us to improve the agreement with the experiment (curve 2). However, the calculations by Arenhövel (see in [9]) have shown the taking account of FSI (curve 3) leads to a better agreement with the experiments without application of relativistic substitutions.

Conclusion

The tensor analysing power is the very sensitive to the mechanism of a reaction. So in order to use the polarization experiments for the investigations of exotic degrees of freedom of a nucleus, it is necessary to take into account the nuclear effects and first of all the final state interaction of secondary particles.

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