ОБЪЕДИНЕННЫЙ
ИНСТИТУТ
ЯДЕРНЫХ
ИССЛЕДОВАНИЙ

Дубна

E2-97-190

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COMPLETE EXPERIMENT FOR *dp* AND ^{3}He,*d* BACKWARD ELASTIC SCATTERING

Submitted to «Few-Body Systems»

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1997

1 INTRODUCTION

The study of the lightest nuclei structure remains the problem of extreme importance in modern physics, and a wide program is envisaged to investigate it using electron probes.

On the other hand, such strong reactions as inclusive breakup of lightest nuclei at zero angle are also expected to be quite a reliable source of information about their structure. The kinematical limit of such reactions is backward elastic scattering (BES). An important advantage of the both breakup reactions and BES is that the measured fragment momentum is directly connected to the argument of the nuclear wave function in the momentum space. That is not so, for example, for elastic *ed* scattering. In the energy range of a few GeV the squared 4-momentum transfer t in BES is much larger in comparison with the squared 4-momentum transfer u, and it is commonly accepted that the u-channel predominates in this reaction.

The momentum distributions of nuclear fragments extracted from disintegration experiments using both electron and hadron probes are quite similar even in the region where they contradict seriously to the expectations based on the Impulse Approximation (IA).

As it is shown in refs.[1, 2, 3], the proton momentum distributions, extracted both from deuteron breakup and backward elastic dp scattering deviating from the IA expectations as much as twice at k of 0.3-0.4 GeV/c, are in good agreement with one another and the distribution extracted from the $d(e, e'p)$.

The resemblance of the deuteron momentum distributions extracted from the cross sections of $^3He(e, e'd)$ and $A(^3He, d)$ reactions is discussed in refs.[4, 5].

The triton distributions extracted from the $A(^4He, t)$[6] and $^4He(e, e't)$[7] are quite similar even in the region where the deviation from the IA expectations is a factor of several orders. This circumstance makes one to doubt that meson exchange currents (this effect is negligible for reactions with hadron probes) are the main source of discrepancy between the IA calculations and experimental data[7].

The substantial progress is achieved in measuring of polarization observables both in the deuteron breakup and backward elastic dp scattering at Saclay[8, 9] and Dubna[10, 11]. The combined analysis of T_{20} and the coefficient of polarization transfer data shows that the discussed processes can not be described in the framework of the IA until the deuteron is considered as the nucleon-nucleon system, described by only S- and D-waves[9, 11]. The experimental data on these two reactions have revealed quite a different behavior starting from 0.2 GeV/c.

At present the question whether the observed effects are induced mostly by unknown peculiarities of the deuteron or by the reaction mechanism nonadequate to the IA, is unsolvable unambiguously in the framework of available information and remains rather a subject of believing. So, it would be natural to study new polarization observables to figure out the situation. While the list of useful polarization observables for the deuteron breakup reaction is practically exhausted, a measurement of any new polarization observable in BES will be fruitful in understanding the deuteron structure. As it was shown in ref.[12], BES for particles with spins of 1 and 1/2 can be described by only four independent complex amplitudes. To determine all of them, even 7 correctly chosen polarization observables would be enough. We discuss here mainly backward elastic dp scattering. But all of the relations deduced here are valid also for backward elastic $^3He\ d$ scattering, which can become actual in the nearest future.

Of course, the realization of the complete experiment (i.e. the set of experiments allowing to determine unambiguously all components of the matrix element) will not provide exhaustive information about the deuteron structure. For instance, only some of the 6 components of the deuteron wave function (DWF) considered in ref.[13] contribute to the process under discussion. But investigations using only electron probes would not give a complete knowledge of the deuteron structure either. There is a number of problems which cannot be resolved unambiguously in the framework of this program. It is enough to mention the problem of meson exchange currents. So, we believe, the complete experiment for BES would be necessary to understand better the deuteron structure and, in particular, clarify the following aspects:

- relative role of different reaction mechanisms, such as ONE, three nucleon resonances, interaction in the initial and final states etc., including the study of the $d \to N + R$ vertex, where R is the so called fermion Regge pole[14, 15].
- separation not only of $S-$ and $D-$ wave components of the DWF, but also of a possible admixture of $P-$wave components[16], isobaric configurations, quark degrees of freedom[17].

The analysis of the complete experiment has been carried out in terms of model-independent parametrization of the spin structure of collinear backward dp collisions. Such a formalism is not connected directly either to the deuteron model or the reaction mechanism. Of course, the final goal is to connect the completely determined matrix element with an adequate model of the deuteron. But that is a subject of a separate investigation, and here we touch upon only trivial relations between these two things.

For the first time a connection of polarization observables in this reaction (T_{20}) with S- and D-wave components of the DWF was considered in the framework of the IA in ref.[18]. For the first time a model-independent analysis to calculate some of polarization observables was applied in ref.[12]. The IA expectations for some additional polarization observables were obtained in ref.[19]. A model-independent analysis of all possible cross section asymmetries was done in ref.[14]. An interesting attempt to explain the obtained experimental data was undertaken in ref.[20]. One more polarization observable was considered there as well.

In this paper we take the complete set of polarization observables connected to polarization of one of the final particles. Double and triple spin correlations are considered. The IA expectations for the majority of them are given. As it is shown below, about fifty polarization observables are possible for BES. Of course, this set is too overdetermined respectively the complete experiment, but the description of each of the observables is necessary to build a reasonable strategy of measurements. We mean a compromise in choosing between the minimal set of observables and a more wide set of the less complicated measurements.

We have managed to select the minimal set of measurements to realize the complete experiment.

Furthermore, in the conclusion we enumerate the accelerator facilities where the program of the complete experiment for the $d + p \to p + d$ reaction could be realized in one or another degree.

This paper is the extended version of the report[21].

2 FORMALISM

The process of elastic scattering of particles with spins of 1 and 1/2 at an arbitrary angle is determined by 12 independent complex amplitudes[22]. The collinearity condition when the total helicity of interacting particles is conserved, reduce the number of independent amplitudes to 4. In terms of helicity amplitudes $F_{\lambda_d \lambda_p \to \lambda_{d'} \lambda_{p'}}$ these are

$$\begin{array}{ll} F_{++\to++}, & F_{0+\to0+}, \\ F_{0+\to+-}, & F_{-+\to-+}, \end{array} \tag{1}$$

where $\lambda_d(\lambda_p)$ corresponds to the deuteron (proton) spin projection onto the beam direction (+1,0,-1 and $\pm\frac{1}{2}$ for deuterons and protons, respectively).

Any set of the amplitudes connected to the helicity amplitudes via an arbitrary linear transformation is acceptable, in general, to describe the process under consideration. Choosing scalar amplitudes $g_i(s)$, we proceed from the maximum available simplification of calculations.

In terms of the chosen amplitudes the total amplitude has the following form:

$$\begin{aligned} \mathcal{M} &= \chi_2^\dagger M \chi_1, \quad M = A + i\sigma B, & (2)\\ A &= g_1(s)[U_1U_2^* - (kU_1)(kU_2^*)] + g_2(s)(kU_1)(kU_2^*), \\ B &= g_3(s)[U_1 \times U_2^* - k(kU_1 \times U_2^*)] + g_4(s)k(kU_1 \times U_2^*), \end{aligned}$$

where $U_1(U_2)$ is a vector of the initial (final) deuteron polarization, $\chi_1(\chi_2)$ is a two-component spinor of the initial (final) proton, σ are Pauli matrices, s is the Mandelstam's variable (squared total energy), k is a unit vector along the beam direction.

Amplitudes g_i are related to the helicity ones as follows:

$$\begin{aligned} F_{++\to++} &= g_1(s) + g_4(s), \qquad F_{0+\to0+} = g_2(s), & (3)\\ F_{0+\to+-} &= -\sqrt{2}g_3(s), \qquad F_{-+\to-+} = g_1(s) - g_4(s). \end{aligned}$$

It is clear from Eq. (3), that $g_1(s)$, $g_2(s)$ and $g_4(s)$ do not change the transversal ($g_1(s)$ and $g_4(s)$) or longitudinal ($g_2(s)$) polarization of the initial deuteron, and $g_3(s)$ describes the transition between the transversely (longitudinally) polarized initial and final longitudinally (transversely) polarized deuterons. In the latter case the proton spin is to be reversed.

We use the following parametrization of the initial polarization states:

$$\rho = \frac{1}{2}(1 + \sigma P) \qquad (4)$$

for protons, where P is a 3-pseudovector of the initial proton polarization, and

$$\rho_{ab} = U_{1a}U_{1b}^* = \frac{1}{3}(\delta_{ab} - i\frac{3}{2}\varepsilon_{abc}S_c - Q_{ab}), \qquad (5)$$
$$Q_{ab} = Q_{ba}, \qquad Q_{aa} = 0$$

for deuterons, where pseudovector S and symmetrical tensor Q_{ab} characterize the (vector) polarization and (tensor) alignment of the initial deuterons. We shall denote the final particle polarizations by the same letters but primed.

Typical generalized Feynman graphs describing this process are shown in Fig.1. The graph (a) is connected to such vertices as $d \to p + n$ or $d \to p + N^*$, where N^* is a nucleon-type resonance.

The vertex $p \to d + \bar{n}$ also emerges in the relativistic consideration[16]. In all cases except X is the fermion Regge pole[14, 15], the graph (a) is described by real amplitudes. The second-order graphs (b) and (c) are connected to such vertices as $d \to \Delta + \Delta$[23], but X and Y can be accepted as some colored objects. Amplitudes g_i are complex in this case.

Here we consider in a more detailed way only the generalized graph (a). The spin structure of the $d \to p + N^*$ vertex, where N^* has the quantum numbers

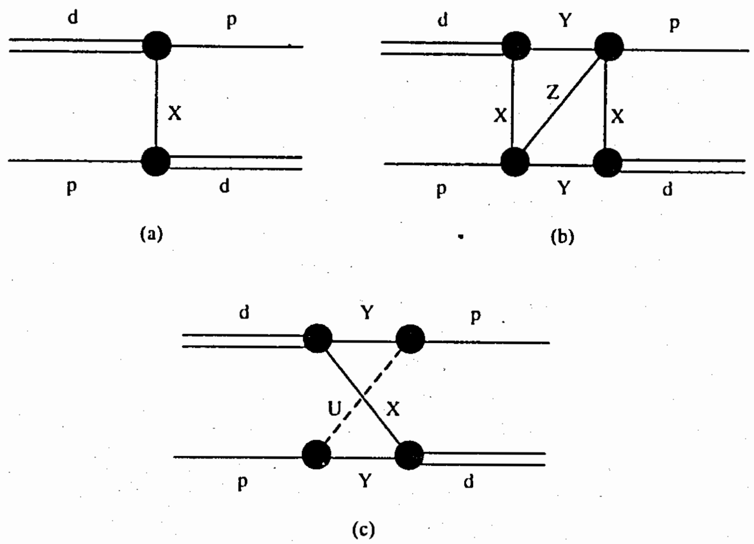

Figure 1. Generalized first- and second-order Feynman graphs corresponding to the $dp \to pd$ reaction. Solid and dashed lines are baryons and mesons, respectively.

of the neutron, namely $J^P = \frac{1}{2}^+$, is described by S- and $D-$ waves. In case of $J^P = \frac{1}{2}^-$ (including the $p \to d + \bar{n}$ vertex) the vertex spin structure is linear in vector k and is described by two P-waves with spins of the $p + N^*$ $(d + \bar{n})$ system of 0 and 1 (1/2 and 3/2).

The corresponding matrix element can be written as

$$\begin{aligned} \mathcal{M} &= \chi_2^\dagger(M_{SD} + M_P)\chi_1, & (6)\\ M_{SD} &= [a(s)\sigma U_1 + \{b(s) - a(s)\}(\sigma k)(kU_1)] \\ &\times [a(s)\sigma U_2^* + \{b(s) - a(s)\}(\sigma k)(kU_2^*)], \\ M_P &= [p_1(s)kU_1 + ip_2(s)\sigma U_1 \times k] \times [p_1(s)kU_2^* - ip_2(s)\sigma U_2^* \times k], \end{aligned}$$

where $a(s)$, $b(s)$, $p_1(s)$ and $p_2(s)$ are real.

Comparing the matrix element (6) with the general structure (2), the amplitudes $g_i(s)$ are found to be related to the newly introduced ones with the expressions

$$\begin{aligned} g_1 &= a^2 + p_2^2, \quad g_2 = b^2 + p_1^2, & (7)\\ g_3 &= ab - p_1p_2, \quad g_4 = a^2 - p_2^2. \end{aligned}$$

If the contribution of M_P is negligible, then the following relations take place:

$$g_1 = g_4, \quad g_1 g_2 = g_3^2. \tag{8}$$

So, if there is some region of s, where amplitudes $g_i(s)$ are almost real, it will be difficult to interpret inequality $g_1 \neq g_4$ (if it is revealed) in another way but as a signal about P-wave components in the deuteron.

3 POLARIZATION OBSERVABLES

A complete set of vector-tensor polarization correlations considered below is restricted mostly by the $P-$invariance of strong interaction and collinearity conditions as well.

The polarization structure functions (PSF) as coefficients near the vector-tensor products are denoted as follows. Letters in the line denote the polarization states being measured. These are p, s, q, i.e., the same but small letters introduced to denote the initial particle polarizations. Superscripts correspond to the implied initial polarization state. These are P, S, Q, PS and PQ. Within this definition an arbitrary space orientation of the initial polarizations can be spanned by several independent vector-tensor products. We distinguish the corresponding PSF using the lower numerical indices. In the framework of our approach it is easy to see that a number of specific measurements beyond of the set of standard polarization observables can be suggested (see Appendix A). That is why we don't follow exactly to commonly accepted denotations[24, 22].

To make formulae more compact, subsidiary vectors $\boldsymbol{Q}$ and $\boldsymbol{Q_P}$ are introduced:

$$Q_a = Q_{ab}k_b, \qquad Q_{Pa} = Q_{ab}P_b. \tag{9}$$

3.1 *Cross section asymmetries*

The dependence of the cross section on the initial state polarizations can be expressed as:

$$\begin{aligned} \frac{d\sigma}{d\Omega} &= \left(\frac{d\sigma}{d\Omega}\right)_0 F, \\ F &= [1 + a^Q \boldsymbol{Qk} + a_1^{PS}\boldsymbol{PS} + a_2^{PS}(\boldsymbol{kP})(\boldsymbol{kS}) + a^{PQ}\boldsymbol{kP}\times\boldsymbol{Q}], \end{aligned} \tag{10}$$

where $(d\sigma/d\Omega)_0$ is the differential cross section for unpolarized particles in the initial state.

The PSF a^Q characterizes the tensor analyzing power of the considered reaction (when the aligned deuterons interact with unpolarized protons).

The PSF a_1^{PS}, a_1^{PS}, a^{PQ} determine the asymmetries of cross sections induced by spin correlations between the initial particles.

The PSF a^{PQ} considered earlier in ref.[14], characterizes the simplest $T-$odd correlation stipulated by the nontrivial mutual orientation of the deuteron alignment and proton polarization in the initial state. It should be mentioned that nonzero effect for such a correlation in the total $\vec{d}\vec{p}$ cross section could be a signal of real T-invariance violation[25]. But for each separate channel of the $\vec{d}\vec{p}$ collision the unitarity condition is not obligatory and a possible source of nonzero effect is more trivial: if a process is described by more than one complex amplitude, the phase shift between them leads to the effect being considered. In our case effects of that type could achieve dozens of percents.

After summing over polarizations of final particles, $(d\sigma/d\Omega)_o$ can be expressed via scalar amplitudes $g_i(s)$ as:

$$\left(\frac{d\sigma}{d\Omega}\right)_o = D = \frac{1}{3}\left(2|g_1|^2 + |g_2|^2 + 4|g_3|^2 + 2|g_4|^2\right), \tag{11}$$

and the PSF a_i^{XY} as:

$$\begin{aligned} a^Q &= \frac{1}{3D}\left(|g_1|^2 - |g_2|^2 - |g_3|^2 + |g_4|^2\right), \\ a_1^{PS} &= \frac{1}{D}\mathrm{Re}(g_1 + g_2 - g_4)g_3^*, \\ a_2^{PS} &= \frac{1}{D}\mathrm{Re}[2g_1g_4^* - (g_1 + g_2 + g_3 - g_4)g_3^*], \\ a^{PQ} &= \frac{2}{3D}\mathrm{Im}(g_1 - g_2 + g_4)g_3^*. \end{aligned} \tag{12}$$

3.2 *Final proton polarization*

The final proton polarization can be presented as a sum of vectors:

$$\boldsymbol{P}' = \boldsymbol{P}^P + \boldsymbol{P}^S + \boldsymbol{P}^Q + \boldsymbol{P}^{PS} + \boldsymbol{P}^{PQ}, \tag{13}$$

where

$$\begin{aligned} \boldsymbol{P}^P &= p_1^P\boldsymbol{P} + p_2^P\boldsymbol{k}(\boldsymbol{kP}), \\ \boldsymbol{P}^S &= p_1^S\boldsymbol{S} + p_2^S\boldsymbol{k}(\boldsymbol{kS}), \\ \boldsymbol{P}^Q &= p^Q\boldsymbol{Q}\times\boldsymbol{k}, \\ \boldsymbol{P}^{PS} &= p_1^{PS}\boldsymbol{P}\times\boldsymbol{S} + p_2^{PS}\boldsymbol{k}(\boldsymbol{kP}\times\boldsymbol{S}) + p_3^{PS}(\boldsymbol{kS})\boldsymbol{k}\times\boldsymbol{P}, \\ \boldsymbol{P}^{PQ} &= p_1^{PQ}\boldsymbol{P}(\boldsymbol{Qk}) + p_2^{PQ}\boldsymbol{k}(\boldsymbol{kP})(\boldsymbol{Qk}) + p_3^{PQ}\boldsymbol{Q}(\boldsymbol{kP}) \\ &+ p_4^{PQ}\boldsymbol{k}(\boldsymbol{PQ}) + p_5^{PQ}\boldsymbol{Q_P}. \end{aligned} \tag{14}$$

The PSF p_i^{XY} are expressed via the scalar amplitudes g_i as:

$$p_1^P = \frac{1}{3D}\left(2|g_1|^2 + |g_2|^2 - 2|g_4|^2\right), \tag{15}$$

$$p_2^P = \frac{4}{3D}\left(-|g_3|^2 + |g_4|^2\right),$$

$$
\begin{aligned}
p_1^S &= \frac{1}{D}\mathrm{Re}(g_1 + g_2 + g_4)g_3^*, && (16)\\
p_2^S &= \frac{1}{D}\mathrm{Re}\left[2g_1g_4^* - (g_1 + g_2 - g_3 + g_4)g_3^*\right],
\end{aligned}
$$

$$p^Q = \frac{2}{3FD}\mathrm{Im}(-g_1 + g_2 + g_4)g_3^*, \qquad (17)$$

$$
\begin{aligned}
p_1^{PS} &= \frac{1}{FD}\mathrm{Im}(g_1 + g_2 + g_4)g_3^*, \qquad p_2^{PS} = \frac{2}{FD}\mathrm{Im}g_3g_4^*, && (18)\\
p_3^{PS} &= \frac{1}{FD}\mathrm{Im}\left[-2g_1g_4^* + (g_1 + g_2 + g_4)g_3^*\right], && (19)
\end{aligned}
$$

$$
\begin{aligned}
p_1^{PQ} &= \frac{1}{3FD}\left(|g_1|^2 - |g_2|^2 + |g_3|^2 - |g_4|^2\right), && (20)\\
p_2^{PQ} &= \frac{2}{3FD}|g_3 - g_4|^2, \qquad p_3^{PQ} = \frac{2}{3FD}\mathrm{Re}(g_1 - g_2 - g_3 + g_4)g_3^*,\\
p_4^{PQ} &= \frac{2}{3FD}\mathrm{Re}(-g_1 + g_2 - g_3 + g_4)g_3^*, \qquad p_5^{PQ} = \frac{2}{3FD}|g_3|^2,
\end{aligned}
$$

where F and D are defined by Eqs. (10) and (11), respectively.

The IA expectation for p_1^P is firstly considered in ref.[19]. The observable p^Q is firstly considered in ref.[20].

3.3 *Final deuteron polarization*

The dependence of the final deuteron polarization on the polarization of the initial particles, has the same vector-tensor structure as for the final protons. The PSF s_i^{XY} are expressed via amplitudes g_i as:

$$s_1^P = p_1^S, \qquad s_2^P = p_2^S, \qquad (21)$$

$$
\begin{aligned}
s_1^S &= \frac{3}{4D}\left(|g_1|^2 + |g_2|^2 - |g_1 - g_2|^2 + 2|g_3|^2\right), && (22)\\
s_2^S &= \frac{3}{2D}\left(|g_1|^2 - |g_3|^2 + |g_4|^2 - \mathrm{Re}g_1g_2^*\right),
\end{aligned}
$$

$$s^Q = -\frac{1}{FD}\mathrm{Im}g_1g_2^*, \qquad (23)$$

$$
\begin{aligned}
s_1^{PS} &= \frac{3}{2FD}\mathrm{Im}g_2g_4^*, \qquad s_2^{PS} = \frac{3}{2FD}\mathrm{Im}\left[g_1g_3^* - (g_2 - g_3)g_4^*\right], && (24)\\
s_3^{PS} &= \frac{3}{2FD}\mathrm{Im}\left[-g_1g_3^* + (g_2 + g_3)g_4^*\right],
\end{aligned}
$$

$$
\begin{aligned}
s_1^{PQ} &= \frac{1}{FD}\mathrm{Re}(g_1 - g_2)g_3^*, \qquad s_2^{PQ} = -\frac{1}{FD}\mathrm{Re}(g_1 - g_2)(g_3 - g_4)^*, && (25)\\
s_3^{PQ} &= \frac{1}{FD}\mathrm{Re}\left[g_2g_4^* - (g_1 + g_3 - g_4)g_3^*\right],\\
s_4^{PQ} &= 0, \qquad s_5^{PQ} = \frac{1}{FD}\mathrm{Re}(g_1 - g_4)g_3^*.
\end{aligned}
$$

The IA expectation for s_1^S is firstly considered in ref.[26].

3.4 *Final deuteron alignment*

In comparison with Eq. (13), the general expression for the final deuteron alignment Q'_{ab} contains an additional term not connected to the initial state polarizations:

$$Q'_{ab} = Q^0_{ab} + Q^P_{ab} + Q^S_{ab} + Q^Q_{ab} + Q^{PS}_{ab} + Q^{PQ}_{ab}. \qquad (26)$$

Six tensors in Eq. (26) are expressed via vector-tensor products as:

$$
\begin{aligned}
Q^0_{ab} &= q^0(k_ak_b - \frac{1}{3}\delta_{ab}), && (27)\\
Q^P_{ab} &= q^P(k_a[\boldsymbol{k}\times\boldsymbol{P}]_b + k_b[\boldsymbol{k}\times\boldsymbol{P}]_a),\\
Q^S_{ab} &= q^S(k_a[\boldsymbol{k}\times\boldsymbol{S}]_b + k_b[\boldsymbol{k}\times\boldsymbol{S}]_a),\\
Q^Q_{ab} &= q_1^Q Q_{ab} + q_2^Q(k_ak_b - \frac{1}{3}\delta_{ab})(\boldsymbol{Qk}) + q_3^Q(k_aQ_b + k_bQ_a - \frac{2}{3}\delta_{ab}\boldsymbol{Qk}),\\
Q^{PS}_{ab} &= q_1^{PS}(k_ak_b - \frac{1}{3}\delta_{ab})\boldsymbol{PS} + q_2^{PS}(k_ak_b - \frac{1}{3}\delta_{ab})(\boldsymbol{kP})(\boldsymbol{kS}),\\
&+ q_3^{PS}(S_aP_b + S_bP_a - \frac{2}{3}\delta_{ab}\boldsymbol{PS}) + q_4^{PS}(k_aS_b + k_bS_a - \frac{2}{3}\delta_{ab}\boldsymbol{kS})\boldsymbol{kP},\\
&+ q_5^{PS}(k_aP_b + k_bP_a - \frac{2}{3}\delta_{ab}\boldsymbol{kP})\boldsymbol{kS},\\
Q^{PQ}_{ab} &= q_1^{PQ}(k_ak_b - \frac{1}{3}\delta_{ab})\boldsymbol{kQ}\times\boldsymbol{P}\\
&+ q_2^{PQ}(P_a[\boldsymbol{k}\times\boldsymbol{Q}]_b + P_b[\boldsymbol{k}\times\boldsymbol{Q}]_a - \frac{2}{3}\delta_{ab}\boldsymbol{kQ}\times\boldsymbol{P})\\
&+ q_3^{PQ}(Q_a[\boldsymbol{k}\times\boldsymbol{P}]_b + Q_b[\boldsymbol{k}\times\boldsymbol{P}]_a - \frac{2}{3}\delta_{ab}\boldsymbol{kP}\times\boldsymbol{Q})
\end{aligned}
$$

$$
\begin{aligned}
&+ \; q_4^{PQ}(k_a[\boldsymbol{k}\times\boldsymbol{P}]_b + k_b[\boldsymbol{k}\times\boldsymbol{P}]_a)\boldsymbol{Qk} \\
&+ \; q_5^{PQ}(k_a[\boldsymbol{k}\times\boldsymbol{Q}]_b + k_b[\boldsymbol{k}\times\boldsymbol{Q}]_a)\boldsymbol{kP} \\
&+ \; q_6^{PQ}(\varepsilon_{amn}P_mQ_{nb} + \varepsilon_{bmn}P_mQ_{na}) \\
&+ \; q_7^{PQ}(k_a[\boldsymbol{k}\times\boldsymbol{Q_P}]_b + k_b[\boldsymbol{k}\times\boldsymbol{Q_P}]_a) \\
&+ \; q_8^{PQ}(k_aQ_{bm}[\boldsymbol{k}\times\boldsymbol{P}]_m + k_bQ_{am}[\boldsymbol{k}\times\boldsymbol{P}]_m) \\
&+ \; q_9^{PQ}(\varepsilon_{amn}k_mQ_{nb} + \varepsilon_{bmn}k_nQ_{nb})\boldsymbol{kP}.
\end{aligned}
$$

The PSF q_j^{XY} are expressed via the scalar amplitudes g_i as:

$$q^0 = a^Q, \tag{28}$$

$$q^P = \frac{1}{6}p^Q, \tag{29}$$

$$q^S = s^Q \tag{30}$$

$$
\begin{aligned}
q_1^Q &= \frac{1}{3FD}\left(|g_1|^2 - |g_4|^2\right), \qquad q_2^Q = \frac{1}{3FD}|g_1-g_2|^2, \qquad (31)\\
q_3^Q &= \frac{1}{3FD}\left(-|g_1|^2 - |g_3|^2 + |g_4|^2 + \mathrm{Re}g_1g_2^*\right).
\end{aligned}
$$

$$
\begin{aligned}
q_1^{PS} &= \frac{1}{FD}\mathrm{Re}(g_1-g_2)g_3^*, \qquad q_2^{PS} = -\frac{1}{FD}\mathrm{Re}(g_1-g_2)(g_3-g_4)^*, \qquad (32)\\
q_3^{PS} &= \frac{1}{2FD}\mathrm{Re}(g_1+g_4)g_3^*,\\
q_4^{PS} &= \frac{1}{2FD}\mathrm{Re}\left[(-g_1+g_3-g_4)g_3^* + g_2g_4^*\right], \qquad q_5^{PS} = 0,
\end{aligned}
$$

$$
\begin{aligned}
q_2^{PQ} &= \frac{1}{3FD}\mathrm{Im}(-g_1+g_2-g_4)g_3^*, \qquad q_3^{PQ} = \frac{1}{3FD}\mathrm{Im}(g_1-g_2)g_3^*, \qquad (33)\\
q_5^{PQ} &= \frac{1}{3FD}\mathrm{Im}(g_1-g_2)(g_3-g_4)^*, \qquad q_6^{PQ} = \frac{1}{3FD}\mathrm{Im}g_1g_3^*,\\
q_7^{PQ} &= -\frac{1}{3FD}\mathrm{Im}g_3g_4^*, \quad q_1^{PQ} = q_4^{PQ} = q_8^{PQ} = q_9^{PQ} = 0.
\end{aligned}
$$

4 STRATEGY OF MEASUREMENTS

The choice of the least set of experiments to determine completely the matrix element can be varied in dependence on existing experimental conditions. Here we would like to suggest one of possible minimal sets.

There is a number of observables linear in $|g_i|^2$. Four of them will be enough to determine moduli of g_i. As for phase shifts (φ_{ij}), the shortest way to the final goal is to measure observables expressed via $\mathrm{Im}g_ig_j$ (or $\mathrm{Im}(\sum g_i)g_j^*)$), i.e. T-odd ones. Indeed, recalling that

$$\mathrm{Re}g_ig_j^* = |g_i||g_j|\cos\varphi_{ij}, \qquad \mathrm{Im}g_ig_j^* = |g_i||g_j|\sin\varphi_{ij},$$

one can see that these observables are odd functions of φ_{ij} which are free from sign ambiguity in comparison with the observables, expressed via $\mathrm{Re}g_ig_j$. Besides, if the phase shifts are small, the task becomes linear in φ_{ij} ($\sin\varphi \simeq \varphi$), and only three observables should be measured to determine completely the searched matrix element.

Taking into account that one of the observables, depending linearly on $|g_i|^2$, a^Q (T_{20}), has already been measured in a wide energy range[8, 10], the other three are needed. There are only two observables of this sort among double spin correlations. These are p_1^P and p_2^P (Eq. (15)). The simplest triple spin correlations for this purpose are p_1^{PQ} and p_5^{PQ} (Eq. (20)).

The T-odd double spin correlations are a^{PQ} (Eq. (12)), p^Q (or q^P) (Eq. (17)) and s^Q (or q^S) (Eq. (23)).

Except the measurement of p_1^P the suggested experiments to determine moduli of g_i are rather complicated, and one can try to substitute them by a more wide set of more simple experiments. The solution of this task can be varied dependently on existing experimental possibilities.

Apart from the measurement of each new polarization observable is a step (in one or another degree) towards the complete determination of the matrix element, some of them are of particular interest. So, measurements of T-odd observables provide the global estimation of the contribution of such second-order Feynman graphs, as (b) and (c) in Fig.1. If the T-odd effects are revealed to be small at some s, then the deviation of already existing data from the IA calculation can be interpreted merely within the framework of the deuteron structure. The contribution of such an intermediate vertex as $NN \to N\Delta$ (graph (b)) is expected in vicinity of $\sqrt{s} \simeq 3.0$ GeV[23]. The most probable interval of the effects of 3-baryon resonances is $\sqrt{s}$=3 – 3.5 GeV. At higher energies a possible source of complexity of scalar amplitudes is the fermion-Regge-pole (FRP)[15] exchange. In quark language it can be interpreted as a generalized three quark exchange in the u-channel. The phenomenology of FRP was very effective to describe the $\pi + N \to \pi + N$, $\pi + N \to \eta + N$, $\pi + N \to \rho + N$ reactions[27].

A number of polarization observables are sensitive to the contribution of P-waves. It is commonly accepted that the total contribution of the P-waves into the DWF does not exceed 0.5%. It is not realistic to observe effects of such a level studying elastic ed scattering, where polarization observables are expressed via integral of the DWF components. But backward elastic dp scattering is sensitive to local values of the DWF components (at least, in the first order). All realistic DWF models predict intersection of zero by the S-wave. In this region the effects induced by the P-waves could achieve dozens of percent, because the total contribution of the only background in this case, the D-wave, does not exceed 5%. The P-wave sensitivity of a^{PS} was illustrated in[12]. But the most sensitive observables are those which are functions of $(g_1 - g_4)$. These are s_5^{PQ} (Eq. (25)) and q_1^Q (Eq. (31)). In the absence of the P-wave admixture the IA expectations for these observables gives 0.

For the cases when the nonvertical quantization axis of the initial deuteron alignment is implied, the explicit expressions for the final particle polarizations are given in Appendix A.

The connection of observables considered in this section with the well known representation $C_{\alpha,\beta,\gamma,\delta}$[22] and the IA expectation for them are given in Appendix B.

The deuteron constituents internal momenta from 0.2 to 1.0 GeV/c seems to be the most interesting range to investigate this reaction. The corresponding primary beam momentum range is 0.65 – 4.0 GeV/c for the proton beam and deuterium target or 1.3 – 8.0 GeV/c – for the deuteron beam and hydrogen target.

Of course, in realistic conditions of a finite angular acceptance one could expect some effects induced by the rest 8 amplitudes. All these effects comprise as a factor whether $\sin\theta\ cos\phi$ or $\sin^2\theta\cos 2\phi$ (in s.c.m.). So, due to $\sin\theta$, the contribution of the rest 8 amplitudes into the considered process does not exceed the level of 1% within an angular acceptance of $1 - 2^o$. But all relations deduced above are valid with a much higher accuracy. The matter is, within such a small θ-acceptance all statistics is integrated over ϕ. That gives an additional several orders suppression of the background amplitudes due to integral of $\cos\phi$ over ϕ gives 0.

5 CONCLUSIONS

For the first time the complete set of polarization observables including triple spin correlations is considered for backward elastic dp scattering.

While investigating observables, linear in $|g_i|^2$ and T-odd ones, the complete experiment can be reduced to measurements of only seven observables, if the phase shifts between the amplitudes describing the process are not too large.

Under definite conditions (small phase shifts between g_i) the P-wave components of the deuteron can be discovered.

The T-odd observables have proved to be an important source of information about the reaction mechanism. In particular, such an exotic object as the fermion Regge pole could be revealed.

The developed technique allows one to calculate all the IA expectations by a more simple way than using the Clebsch-Gordan coefficients.

The following accelerator facilities are suitable to realize the suggested program. The measurement of a_1^{PS} is planned[28] at the Dubna synchrophasotron, using the polarized deuteron beam and the polarized proton target[29]. The investigation of the internal momenta range from 0.3 to 0.85 GeV/c is envisaged. If the secondary deuterons spectrometer is developed up to a polarimeter, then several additional observables would be measured.

Measurements of a_1^{PS} and a^{PQ} are quite realistic at COSY using the polarized proton beam and polarized deuterium target. The energy range is roughly the same as in Dubna.

A wide program to realize the complete experiment can be developed at KEK, AGS, RHIC and LISS.

Acknowledgement.

The authors would like to express their deep recognition and gratitude to A.M.Baldin and F.Lehar for strong support of this activity, C.F.Perdrisat and V.Punjabi for their efforts to realize the complete experiment. We are also grateful to J.Arvieux, L.S.Azhgirey, S.Belostotsky, A.Boudard, P.D.Eversheim, V.I.Komarov, K.Sistemich, E.A.Strokovsky, E.Tomasi-Gustafsson for fruitful discussions.

This work is supported in part by Russian Foundation for Fundamental researches, grant *No.* 95-02-05043.

A

The most appropriate system to calculate the vector-tensor products given above is the deuteron rest frame. In this system assuming that the z-axis is directed along the quantization axis of the deuteron, the polarization tensor has the form:

$$Q_{ab} = \begin{pmatrix} -Q_{zz}/2 & 0 & 0 \\ 0 & -Q_{zz}/2 & 0 \\ 0 & 0 & Q_{zz} \end{pmatrix}.$$

Using this system, it is easy to see the following properties of vector $Q_a = Q_{ab}m_a$, where m_a is an arbitrary vector. We have $\boldsymbol{Q}||\boldsymbol{m}$, if $\boldsymbol{m}$ is parallel or perpendicular to the z-axis. For an arbitrary angle β between the directions of $\boldsymbol{m}$ and the z-axis we have:

$$\boldsymbol{Qm} = \frac{Q_{zz}|\boldsymbol{m}|}{2}(3\cos^2\beta - 1), \quad \boldsymbol{Q}\times\boldsymbol{m} = \frac{3}{4}Q_{zz}|\boldsymbol{m}|\boldsymbol{n}\sin 2\beta, \qquad \text{(A.1)}$$

where $\boldsymbol{n}$ is a unit vector directed along $\boldsymbol{z}\times\boldsymbol{m}$.

In case of measuring of a^{PQ} (Eq. (12)) we have

$$\frac{d\sigma}{d\Omega} = \left(\frac{d\sigma}{d\Omega}\right)_0 \left[1 + \frac{1}{2}a^Q Q_{zz}(3\cos^2\beta - 1) + \frac{3}{4}a^{PQ}Q_{zz}\boldsymbol{Pn}\sin 2\beta\right]. \qquad (A.2)$$

The final particle polarizations are related to the initial deuteron alignment (Eqs. (17) and (23)) as:

$$\boldsymbol{P}' = \frac{3}{4}p_1^Q Q_{zz}\boldsymbol{n}\sin 2\beta, \qquad \boldsymbol{S}' = \frac{3}{4}s_1^Q Q_{zz}\boldsymbol{n}\sin 2\beta. \qquad (A.3)$$

In case of measuring of the discussed above triple spin correlation (Eq. (25)) the final deuteron polarization depends on the initial state parameters as:

$$\boldsymbol{S}' = s_1^P \boldsymbol{P} + \frac{1}{2}\left[s_1^{PQ}(3\cos^2\beta - 1) + s_5^{PQ}(3\sin^2\beta - 1)\right] Q_{zz}\boldsymbol{P}, \qquad (A.4)$$

where the conditions $\boldsymbol{Pn} = 0$ and $\boldsymbol{Pk} = 0$ are implied. From Eq. (A.4) it is seen that the direct measurement of s_5^{PQ} sensitive to P-waves, is possible under condition $3\cos^2\beta = 1$.

B

The indices α, β of $C_{\alpha,\beta,\gamma,\delta}$ refer to the initial polarizations and indices γ and δ – to the final polarizations of the protons and deuterons, respectively. Double indices correspond to tensor polarizations. Using such subscripts as SL, we imply the quantization axis lying in the SL-plane at 45^o relatively the beam direction (L) in the deuteron rest frame.

The IA expectations are given in terms of a and b related to the amplitudes g_i by Eqs. (7), when amplitudes p_1 and p_2 are neglected. We have

$$a(s) = u(k) + \frac{1}{\sqrt{2}}w(k), \qquad b(s) = u(k) - \sqrt{2}w(k), \qquad (B.1)$$

where $u(k)$ and $w(k)$ are, respectively, S- and D-waves describing whether the $d \to p+n$ or ${}^3He \to d+p$ vertex. The "internal" fragment momentum $k = k(s)$ is a single-valued function of s, but not the same in different approaches. In the nonrelativistic IA, k is simply a final proton (deuteron) momentum in the deuteron (${}^3He$) rest frame. In the relativistic approach k is connected to s via a more complicated chain of formulae given in ref.[2].

The list of the considered observables is restricted by those, which are not connected to measurements of the tensor or longitudinal vector polarization of the secondary particles.

In the framework of ONE the cross section for unpolarized particles has the form of

$$\left(\frac{d\sigma}{d\Omega}\right)_o = \frac{1}{3}(2a^2 + b^2)^2 = 3(u^2 + w^2)^2 = 3\Psi^4. \qquad (B.2)$$

For the single scattering experiments the following relations are valid:

$$\begin{aligned}
C_{0,LL,0,0} &= a^Q \to \frac{a^2 - b^2}{3\Psi^2}, && (B.3)\\
C_{N,N,0,0} &= a_1^{PS} \to \frac{ab^3}{3\Psi^4}, && (B.4)\\
C_{L,L,0,0} &= a_1^{PS} + a_2^{PS} = \frac{2g_1g_4^* - |g_3|^2}{D} \to \frac{2a^2(a^2 - b^2)}{3\Psi^4}, && (B.5)\\
C_{N,SL,0,0} &= a^{PQ} \to 0. && (B.6)
\end{aligned}$$

For the double scattering experiments, when double spin correlations are assumed (the polarization transfers), we have

$$\begin{aligned}
C_{N,0,N,0} &= p_1^P \to \frac{b^4}{9\Psi^4}, && (B.7)\\
C_{N,0,0,N} &= C_{0,N,N,0} = p_1^S \to \frac{ab}{\Psi^2}, && (B.8)\\
C_{0,N,0,N} &= s_1^S \to \frac{a^2b^2}{\Psi^4}, && (B.9)\\
C_{0,SN,N,0} &= p^Q \to 0, && (B.10)\\
C_{0,SN,0,N} &= s^Q \to 0. && (B.11)
\end{aligned}$$

For the selected triple spin correlations the relations are as follows:

$$\begin{aligned}
C_{N,L,S,0} &= p_1^{PS} - p_3^{PS} = \frac{2\mathrm{Im}g_1g_4^*}{FD} \to 0, && (B.12)\\
C_{L,N,S,0} &= p_1^{PS} \to 0, && (B.13)\\
C_{N,L,0,S} &= s_1^{PS} - s_3^{PS} = \frac{3\mathrm{Im}(g_1 - g_4)g_3^*}{2FD} \to 0, && (B.14)\\
C_{L,N,0,S} &= s_1^{PS} \to 0, && (B.15)\\
C_{N,NN,N,0} &= p_5^{PQ} - \frac{1}{2}p_1^{PQ} = -\frac{|g_1|^2 + |g_2|^2 + 3|g_3|^2 + |g_4|^2}{6FD} \\
&\to \frac{1}{F}\frac{b^2(3a^2 + b^2)}{18\Psi^4}, && (B.16)\\
C_{N,LL,N,0} &= p_1^{PQ} - \frac{1}{2}p_5^{PQ} = \frac{|g_1|^2 - |g_2|^2 - |g_4|^2}{3FD} \to -\frac{1}{9F}\frac{b^4}{\Psi^4}, && (B.17)
\end{aligned}$$

$$C_{N,NN,0,N} = s_5^{PQ} - \frac{1}{2}s_1^{PQ} = \frac{\mathrm{Re}(g_1+g_2-2g_4)g_3}{2FD} \to -\frac{1}{F}\frac{ab(a^2-b^2)}{6\Psi^4}, \tag{B.18}$$

$$C_{N,LL,0,N} = s_1^{PQ} - \frac{1}{2}s_5^{PQ} = \frac{\mathrm{Re}(g_1-2g_2+g_4)g_3}{2FD} \to \frac{1}{F}\frac{ab(a^2-b^2)}{3\Psi^4}, \tag{B.19}$$

where F and D are defined by Eqs. (10) and (11), respectively. We have taken observables $C_{\alpha,\beta,\gamma,\delta}$ only as notions neglecting the numerical coefficients used in ref.[22].

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Received by Publishing Department
on June 10, 1997.

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Полный эксперимент в упругом *dp* и ^{3}He,*d* рассеянии назад

Анализируется проблема полного опыта в упругом рассеянии назад частиц со спином 1 и 1/2. Рассмотрены все эффекты, связанные с поляризацией одной или двух начальных и одной из вторичных частиц. Предложен минимальный набор измерений, позволяющий восстановить каждую из четырех амплитуд, описывающих данный процесс. Показано, что некоторые поляризационные характеристики могут быть чувствительны к *P*-волнам в дейтроне. Разработанный математический аппарат позволяет легко рассчитывать ожидаемые эффекты в импульсном приближении. Дан краткий обзор по географии осуществления полного эксперимента.

Работа выполнена в Лаборатории высоких энергий ОИЯИ.

Препринт Объединенного института ядерных исследований. Дубна, 1997

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Complete Experiment for *dp* and ^{3}He,*d* Backward Elastic Scattering

The problem of the complete experiment in backward elastic scattering of particle with spins of 1 and 1/2 is considered. For the first time all possible effects caused by polarization of one or two initial and one final particles are touched upon. The minimal set of measurements allowing to reconstruct each of four amplitudes describing this process is suggested. Some observables are expected to be sensitive to such deuteron peculiarities as possible *P*-wave components. The developed technique is a good tool to calculate easily the expectations in the Impulse Approximation for any observables. The geography of the complete experiment is briefly discussed.

The investigation has been performed at the Laboratory of High Energies, JINR.

Preprint of the Joint Institute for Nuclear Research. Dubna, 1997