ОБЪЕДИНЕННЫЙ
ИНСТИТУТ
ЯДЕРНЫХ
ИССЛЕДОВАНИЙ

Дубна

E4-96-328

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THE COMPLETE EXPERIMENT FOR BACKWARD ELASTIC *dp* SCATTERING

Submitted to «Physical Review C»

*National Science Center — Kharkov Institute of Physics and Technology, 310108, Kharkov, Ukraine

1996

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Полный эксперимент в упругом *dp*-рассеянии назад

Анализируется проблема полного опыта в упругом *dp*-рассеянии назад. Рассмотрены все эффекты, связанные с поляризацией одной или двух начальных и одной из вторичных частиц. Показано, что минимальный набор измерений, позволяющий восстановить каждую из четырех амплитуд, описывающих данный процесс, не включает слишком сложных экспериментов и вполне реалистичен на данном этапе. Дан краткий обзор по географии осуществления полного эксперимента.

Работа выполнена в Лаборатории высоких энергий ОИЯИ.

Препринт Объединенного института ядерных исследований. Дубна, 1996

Rekalo M.P., Piskunov N.M., Sitnik I.M. E4-96-328
The Complete Experiment for Backward Elastic *dp* Scattering

The problem of the complete experiment in backward elastic *dp* scattering is analyzed. All effects due to polarization of one or two initial and one of secondary particles are considered. It is shown that the minimal set of measurements allowing to reconstruct each of four amplitudes describing this process does not comprise too complicated experiments and is quite realistic nowadays. The geography of realization of the complete experiment is briefly reviewed.

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

Preprint of the Joint Institute for Nuclear Research. Dubna, 1996

1 Introduction

The reaction of backward elastic dp scattering (180^o in c.m.s.) is one of classical sources of information about the deuteron structure. In GeV region the squared 4-momentum transfer t is much larger, than the squared 4-momentum transfer u, and assumption about u-channel predominance is quite natural. In this approach the Impulse Approximation (IA) become One Nucleon Exchange (ONE) model. Until the deuteron can be treated as a nucleon-nucleon system, the only kinematical parameter of this reaction, squared total energy s, directly connected with the argument of the Deuteron Wave Function (DWF) in the momentum space.

Experimental study of the cross section of this reaction is started decades ago. At the moment, this characteristic of the reaction is investigated up to energies, which corresponds in the framework of ONE to nucleon internal momenta of order of 1 GeV/c[1]. In carried out later investigations of polarization observables, there were achieved the internal momenta of 0.9 GeV/c in measurements of T_{20}[2, 3, 4] and of 0.6 GeV/c in measurements of the polarization transfer coefficient from the deuteron to the proton[4].

At internal momenta of order of 1 GeV/c such a simplified reaction mechanism as ONE is hardly realistic. The description of the deuteron as the nucleon-nucleon system is also not adequate. Attempts to make an evident step in this case, to include quark degrees of freedom, still have not lead to commonly accepted an approach. Additional difficulties are connected with necessity of relativistic description of bound systems. Here the commonly accepted approach also have not found yet. Rather unexpected result of mentioned experimental investigation is a fact that ONE approach become nonadequate already at $\simeq 0.2$ GeV/c for any DWF, comprising only S- and D- wave components of the deuteron[4].

It would be a natural step to study new polarization observables to understand the situation. As was shown in ref.[5], the reaction of backward elastic dp scattering can be described by only four independent complex amplitudes. To define all of them completely, only 6 successfully chosen polarization observables would be sufficient.

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. Say, only part of 6 considered in ref.[6] deuteron components make a contribution to the discussed process. But a wide program of investigation of the deuteron structure, using only electron probes, is also not complete. There is a number of problems, which cannot be solved unambiguously in frameworks of this program. It is sufficient to mention the problem of meson exchange currents. So, we think, the realization of the complete experiment is the necessary step in the direction of understanding of the deuteron structure, which will help to solve the following questions:

- relative roles of different reaction mechanisms, such us ONE, three nucleon resonances, interaction in initial and final state and so forth, including study of structure of the $d \to N + R$ vertex, where R is so called fermion Regge pole, which is an absolutely special object in the deuteron physics[7, 8].

- separation not only of $S-$ and $D-$ wave components of the DWF, but also of possible admixture of $P-$wave components[9], isobaric configurations, quark degrees of freedom[10].

Of course, the analysis of the complete experiment for collinear backward dp collisions must be fulfilled in terms of model independent parametrization of the spin structure of the discussed process. Such a formalism is not connected directly either with the deuteron model or the reaction mechanism. Firstly a connection of polarization observables in this reaction (T_{20}) with the DWF components was considered in ref.[11]. The spin-spin correlation of initial particles in framework of model independent analysis was considered in ref.[5]. Full analysis of all possible cross section asymmetries was done in ref.[7]. Some additional polarization observables in frameworks of the IA were considered in ref.[12]. An attempt to explain mentioned polarization experiments is done in ref.[13].

In this paper we are including into consideration full set of polarization observables connected with polarization of one of final particles. Double and triple spin correlations are considered. In this analysis we use the formalism of polarization structure functions in spirit of G.Ohlsen[14]. We try to develop an approach, most adequate to bring to light consequences of strong interaction symmetries in conditions of collinear kinematics and to find nontrivial polarization effects surviving in this kinematics.

Then we try to select the simplest set of measurements for realization of the complete experiment. To evaluate roughly expected asymmetries for the selected experiments, the expressions, deduced in the IA approach, are given.

In conclusion we briefly touch the problem of realization of the complete experiment for the $d+p \to p+d$ reaction at different accelerators of the world.

2 Formalism

The process of elastic dp scattering at an arbitrary angle in general case is defined by 12 independent complex amplitudes[15] and so, at least 23 polarization observables as a function of two variables must be measured in the complete experiment.

The problem of the complete experiment is much simpler in case of forward ($\theta = 0^o$) and backward ($\theta = 180^o$) scattering, when the total helicity of interacting particles is conserved. In this case the spin structure of the full amplitude is defined by only four amplitudes (which are different for two mentioned above kinematical conditions).

There are some equivalent sets of amplitudes, suitable for the description of the discussed process. Making our choice of scalar amplitudes $g_i(s)$, we proceed from maximum available simplification of calculations.

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

$$\mathcal{M} = \chi_2^\dagger M \chi_1, \quad M = A + i\vec{\sigma}\cdot\mathbf{B}, \tag{1}$$
$$A = g_1(s)[\mathbf{U}_1\mathbf{U}_2^* - (\mathbf{k}\mathbf{U}_1)(\mathbf{k}\mathbf{U}_2^*)] + g_2(s)(\mathbf{k}\mathbf{U}_1)(\mathbf{k}\mathbf{U}_2^*),$$
$$\mathbf{B} = g_3(s)[\mathbf{U}_1\times\mathbf{U}_2^* - \mathbf{k}(\mathbf{k}\mathbf{U}_1\times\mathbf{U}_2^*)] + g_4(s)\mathbf{k}(\mathbf{k}\mathbf{U}_1\times\mathbf{U}_2^*),$$

where $\mathbf{U}_1(\mathbf{U}_2)$ is the spin vector of the initial (final) deuteron, $\chi_1(\chi_2)$ is the two-component spinor of the initial (final) proton, $\vec{\sigma}$ are the Pauli matrices, s is the Mandelstam's variable (squared total energy), $\mathbf{k}$ is the unit vector along the beam direction.

The amplitudes g_i relate to helicity ones $F_{\lambda_d\lambda_p\to\lambda_{d'}\lambda_{p'}}$ by the following way:

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

where $\lambda_d(\lambda_p)$ corresponds to the deuteron (proton) spin projection onto the beam direction (+1,0,-1 for deuterons and $\pm\frac{1}{2}$ for protons). It is easy to see from (2), 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 deuteron and longitudinally (transversely) polarized final one. In the latter case the proton spin must be reversed.

We accept the following parametrization of the initial polarization states. These are

$$\rho = \frac{1}{2}(1+\vec{\sigma}\mathbf{P}) \tag{3}$$

for protons, where $\mathbf{P}$ is 3-vector of initial proton polarization, and

$$\rho_{ab} = U_{1a}U_{1b}^* = \frac{1}{3}(\delta_{ab} - i\frac{3}{2}\varepsilon_{abc}S_c - Q_{ab}), \tag{4}$$
$$Q_{ab} = Q_{ba}, \qquad Q_{aa} = 0.$$

for deuterons, where pseudovector $\mathbf{S}$ and symmetrical tensor Q_{ab} characterize the vector and tensor initial deuteron polarization. We will denote polarization of secondary particles by the same letters but provided by indexes.

The full set of vector-tensor polarization correlations, considered below, is restricted mostly by $P-$ invariance of strong interaction and also by presence of only one momentum direction (3-vector $\mathbf{k}$).

To make formulae more compact we use subsidiary vectors $\mathbf{Q}$, $\mathbf{Q}_P$, defined as

$$Q_a = Q_{ab}k_b, \qquad Q_{Pa} = Q_{ab}P_b. \tag{5}$$

3 Cross section asymmetries

The dependence of the cross section on polarization $\mathbf{P}$ of initial protons and vector ($\mathbf{S}$) and tensor (Q_{ab}) polarization of initial deuterons can be expressed as:

$$\begin{aligned} \frac{d\sigma}{d\Omega} &= \left(\frac{d\sigma}{d\Omega}\right)_0 F, \\ F &= [1 + a_0\mathbf{Q}\mathbf{k} + a_1\mathbf{P}\mathbf{S} + a_2(\mathbf{k}\mathbf{P})(\mathbf{k}\mathbf{S}) + a_3\mathbf{k}\mathbf{P}\times\mathbf{Q}], \end{aligned} \tag{6}$$

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

The PSF a_o characterizes the tensor analyzing power of the considered reaction (when tensor polarized deuterons interact with unpolarized protons).

The PSF $a_1 - a_3$ determine the asymmetry of cross sections induced by spin correlation between initial particles.

The PSF a_3 characterizes the simplest $T-$odd correlation in the $d+p \to p+d$ reaction, stipulated by tensor polarization of initial deuterons and polarization of initial protons. The feasibility of measuring of this observable is analyzed in ref.[7]. It is necessary to stress here, that nonzero effect for such polarization correlation in the total $\vec{d}\vec{p}$ cross section would be a signal of real T-invariance violation[16]. The search of T-invariance violation in this way is planned[17]. But for each channel of the $\vec{d}\vec{p}$ collision the possible source of nonzero effect is more trivial: if a process is described by more than one complex amplitudes, the phase shift between them lead to considered effect. In our case such an effect could achieve decades of percents.

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

$$\left(\frac{d\sigma}{d\Omega}\right)_o = \frac{1}{3}\left(2|g_1|^2 + |g_2|^2 + 4|g_3|^2 + 2|g_4|^2\right), \quad (7)$$

and polarization structure functions (PSF) a_i as:

$$\begin{aligned} a_o\left(\frac{d\sigma}{d\Omega}\right)_o &= \frac{1}{3}\left(|g_1|^2 - |g_2|^2 - |g_3|^2 + |g_4|^2\right), \quad (8)\\ a_1\left(\frac{d\sigma}{d\Omega}\right)_o &= Re(g_1 + g_2 - g_4)g_3^*,\\ a_2\left(\frac{d\sigma}{d\Omega}\right)_o &= Re[2g_1g_4^* - (g_1 + g_2 + g_3 - g_4)g_3^*],\\ a_3\left(\frac{d\sigma}{d\Omega}\right)_o &= \frac{2}{3}Im(g_1 - g_2 + g_4)g_3^*. \end{aligned}$$

4 Polarization of scattered protons

We write the dependence of a polarization of scattered protons on polarizations of initial particles in the following general form:

$$\mathbf{P}_2 = \mathbf{b}_1(\mathbf{P}) + \mathbf{b}_2(\mathbf{S}) + \mathbf{b}_3(Q_{ab}) + \mathbf{b}_4(\mathbf{P},\mathbf{S}) + \mathbf{b}_5(\mathbf{P},Q_{ab}). \quad (9)$$

The connection of the vectors $\mathbf{b}_i$ with PSF b_{ij} is:

$$\begin{aligned} \mathbf{b}_1 &= b_{11}\mathbf{P} + b_{12}\mathbf{k}(\mathbf{kP}), \quad (10)\\ \mathbf{b}_2 &= b_{21}\mathbf{S} + b_{22}\mathbf{k}(\mathbf{kS}),\\ \mathbf{b}_3 &= b_{31}\mathbf{Q}\times\mathbf{k},\\ \mathbf{b}_4 &= b_{41}\mathbf{P}\times\mathbf{S} + b_{42}\mathbf{k}(\mathbf{kP}\times\mathbf{S}) + b_{43}(\mathbf{kS})\mathbf{k}\times\mathbf{P},\\ \mathbf{b}_5 &= b_{51}\mathbf{P}(\mathbf{Qk}) + b_{52}\mathbf{k}(\mathbf{kP})(\mathbf{Qk}) + b_{53}\mathbf{Q}(\mathbf{kP}) + b_{54}\mathbf{k}(\mathbf{PQ}) + b_{55}\mathbf{Q}_P. \end{aligned}$$

PSF b_{ij} relate to the scalar amplitudes g_i as:

$$\begin{aligned} b_{11}\frac{d\sigma}{d\Omega} &= \frac{1}{3}\left(2|g_1|^2 + |g_2|^2 - 2|g_4|^2\right), \quad (11)\\ b_{12}\frac{d\sigma}{d\Omega} &= \frac{4}{3}\left(-|g_3|^2 + |g_4|^2\right), \end{aligned}$$

$$\begin{aligned} b_{21}\frac{d\sigma}{d\Omega} &= Re(g_1 + g_2 + g_4)g_3^*, \quad (12)\\ b_{22}\frac{d\sigma}{d\Omega} &= Re\left[2g_1g_4^* - (g_1 + g_2 - g_3 + g_4)g_3^*\right], \end{aligned}$$

$$b_{31} = \frac{2}{3}Im(-g_1 + g_2 + g_4)g_3^*, \quad (13)$$

$$\begin{aligned} b_{41}\frac{d\sigma}{d\Omega} &= Im(g_1 + g_2 + g_4)g_3^*, \quad b_{42}\frac{d\sigma}{d\Omega} = 2Img_3g_4^*, \quad (14)\\ b_{43}\frac{d\sigma}{d\Omega} &= Im\left[-2g_1g_4^* + (g_1 + g_2 + g_4)g_3^*\right], \end{aligned}$$

$$\begin{aligned} b_{51}\frac{d\sigma}{d\Omega} &= \frac{1}{3}\left(|g_1|^2 - |g_2|^2 + |g_3|^2 - |g_4|^2\right), \quad (15)\\ b_{52}\frac{d\sigma}{d\Omega} &= \frac{2}{3}|g_3 - g_4|^2, \quad b_{53}\frac{d\sigma}{d\Omega} = \frac{2}{3}Re(g_1 - g_2 - g_3 + g_4)g_3^*,\\ b_{54}\frac{d\sigma}{d\Omega} &= \frac{2}{3}Re(-g_1 + g_2 - g_3 + g_4)g_3^*, \quad b_{55}\frac{d\sigma}{d\Omega} = \frac{2}{3}|g_3|^2, \end{aligned}$$

where $d\sigma/d\Omega$ is the cross section, defined in (6).

First indexes of defined above PSF (a_i, b_{ij}) correspond to different power of correlations. The index 0 corresponds to single, 1,2,3 to double and 4,5 to triple spin correlations, respectively. The same rule concerns PSF, introduced below.

5 Vector polarization of scattered deuterons

The dependence of vector polarization ($\mathbf{S}_2$) of scattered deuterons from the polarization of initial particles can be described by following general formula:

$$\mathbf{S}_2 = \mathbf{c}(\mathbf{P}) + \mathbf{c}_2(\mathbf{S}) + \mathbf{c}_3(Q_{ab}) + \mathbf{c}_4(\mathbf{P},\mathbf{S}) + \mathbf{c}_5(\mathbf{P},Q_{ab}) \quad (16)$$

The connection of vectors $\mathbf{c}_i$ with PSF c_{ij} is the same as between $\mathbf{b}_i$ and b_{ij} in formulae (10). PSF c_{ij} are defined by following combinations of scalar amplitudes g_i:

$$c_{11} = b_{21}, \quad c_{12} = b_{22} \quad (17)$$

$$\begin{aligned} c_{21}\frac{d\sigma}{d\Omega} &= \frac{3}{4}\left(|g_1|^2 + |g_2|^2 - |g_1 - g_2|^2 + 2|g_3|^2\right), \quad (18)\\ c_{22}\frac{d\sigma}{d\Omega} &= \frac{3}{2}\left(|g_1|^2 - |g_3|^2 + |g_4|^2 - Reg_1g_2^*\right) \end{aligned}$$

$$c_{31}\frac{d\sigma}{d\Omega} = -Img_1g_2^*, \quad (19)$$

$$\begin{aligned} c_{41}\frac{d\sigma}{d\Omega} &= \frac{3}{2}Img_2g_4^*, \quad c_{42}\frac{d\sigma}{d\Omega} = \frac{3}{2}Im\left[g_1g_3^* - (g_2 - g_3)g_4^*\right], \quad (20)\\ c_{43}\frac{d\sigma}{d\Omega} &= \frac{3}{2}Im\left[-g_1g_3^* + (g_2 + g_3)g_4^*\right], \end{aligned}$$

$$\begin{aligned} c_{51}\frac{d\sigma}{d\Omega} &= Re(g_1 - g_2)g_3^*, \quad c_{52}\frac{d\sigma}{d\Omega} = -Re(g_1 - g_2)(g_3 - g_4)^*, \quad (21)\\ c_{53}\frac{d\sigma}{d\Omega} &= Re\left[g_2g_4^* - (g_1 + g_3 - g_4)g_3^*\right],\\ c_{54} &= 0, \quad c_{55}\frac{d\sigma}{d\Omega} = Re(g_1 - g_4)g_3^*. \end{aligned}$$

6 Tensor polarization of scattered deuterons

For tensor polarization Q_{2ab} of scattered deuterons the following general formula is valid:

$$Q_{2ab} = d_{0ab} + d_{1ab}(\mathbf{P}) + d_{2ab}(\mathbf{S}) + d_{3ab}(Q_{ab}) + d_{4ab}(\mathbf{P},\mathbf{S}) + d_{5ab}(\mathbf{P},Q_{ab}) \quad (22)$$

Six tensors in (22) can be expressed through PSF d_{ij}:

$$
\begin{aligned}
d_{0ab} &= d_{01}(k_a k_b - \frac{1}{3}\delta_{ab}), \qquad (23)\\
d_{1ab} &= d_{11}(k_a[\mathbf{k}\times\mathbf{P}]_b + k_b[\mathbf{k}\times\mathbf{P}]_a),\\
d_{2ab} &= d_{21}(k_a[\mathbf{S}\times\mathbf{k}]_b + k_b[\mathbf{S}\times\mathbf{k}]_a),\\
d_{3ab} &= d_{31}Q_{ab} + d_{32}(k_a k_b - \frac{1}{3}\delta_{ab})(\mathbf{Qk}) + d_{33}(k_a Q_b + k_b Q_a - \frac{2}{3}\delta_{ab}(\mathbf{Qk})),\\
d_{4ab} &= d_{41}(k_a k_b - \frac{1}{3}\delta_{ab})\mathbf{PS} + d_{42}(k_a k_b - \frac{1}{3}\delta_{ab})(\mathbf{kP})(\mathbf{kS}),\\
&+ d_{43}(S_a P_b + S_b P_a - \frac{2}{3}\delta_{ab}\mathbf{PS}) + d_{44}(k_a S_b + k_b S_a - \frac{2}{3}\delta_{ab}\mathbf{kS})\mathbf{kP},\\
&+ d_{45}(k_a P_b + k_b P_a - \frac{2}{3}\delta_{ab}\mathbf{kP})\mathbf{kS},\\
d_{5ab} &= d_{51}(k_a k_b - \frac{1}{3}\delta_{ab})\mathbf{kQ}\times\mathbf{P}\\
&+ d_{52}(P_a[\mathbf{k}\times\mathbf{Q}]_b + P_b[\mathbf{k}\times\mathbf{Q}]_a - \frac{2}{3}\delta_{ab}\mathbf{kQ}\times\mathbf{P})\\
&+ d_{53}(Q_a[\mathbf{k}\times\mathbf{P}]_b + Q_b[\mathbf{k}\times\mathbf{P}]_a - \frac{2}{3}\delta_{ab}\mathbf{kP}\times\mathbf{Q})\\
&+ d_{54}(k_a[\mathbf{k}\times\mathbf{P}]_b + k_b[\mathbf{k}\times\mathbf{P}]_a)\mathbf{Qk}\\
&+ d_{55}(k_a[\mathbf{k}\times\mathbf{Q}]_b + k_b[\mathbf{k}\times\mathbf{Q}]_a)\mathbf{kP}\\
&+ d_{56}(\varepsilon_{amn}P_m Q_{nb} + \varepsilon_{bmn}P_m Q_{na})\\
&+ d_{57}(k_a[\mathbf{k}\times\mathbf{Q}_P]_b + k_b[\mathbf{k}\times\mathbf{Q}_P]_a)\\
&+ d_{58}(k_a Q_{bm}[\mathbf{k}\times\mathbf{P}]_m + k_b Q_{am}[\mathbf{k}\times\mathbf{P}]_m)\\
&+ d_{59}(\varepsilon_{amn}k_m Q_{nb} + \varepsilon_{bmn}k_n Q_{nb})\mathbf{kP},
\end{aligned}
$$

with following expressions of d_{ij} through g_i:

$$d_{01} = a_0, \qquad (24)$$

$$d_{11}\frac{d\sigma}{d\Omega} = \frac{1}{9}Im(-g_1 + g_2 + g_4)g_3^*, \qquad (25)$$

$$d_{21} = c_{31} \qquad (26)$$

$$
\begin{aligned}
d_{31}\frac{d\sigma}{d\Omega} &= \frac{1}{3}\left(|g_1|^2 - |g_4|^2\right), \qquad d_{32}\frac{d\sigma}{d\Omega} = \frac{1}{3}|g_1 - g_2|^2, \qquad (27)\\
d_{33}\frac{d\sigma}{d\Omega} &= \frac{1}{3}\left(-|g_1|^2 - |g_3|^2 + |g_4|^2 + Reg_1 g_2^*\right).
\end{aligned}
$$

$$
\begin{aligned}
d_{41}\frac{d\sigma}{d\Omega} &= Re(g_1 - g_2)g_3^*, \qquad d_{42}\frac{d\sigma}{d\Omega} = -Re(g_1 - g_2)(g_3 - g_4)^*, \qquad (28)\\
d_{43}\frac{d\sigma}{d\Omega} &= \frac{1}{2}Re(g_1 + g_4)g_3^*,\\
d_{44}\frac{d\sigma}{d\Omega} &= \frac{1}{2}Re\left[(-g_1 + g_3 - g_4)g_3^* + g_2 g_4^*\right], \qquad d_{45} = 0,
\end{aligned}
$$

$$
\begin{aligned}
d_{52}\frac{d\sigma}{d\Omega} &= \frac{1}{3}Im(-g_1 + g_2 - g_4)g_3^*, \qquad d_{53}\frac{d\sigma}{d\Omega} = \frac{1}{3}Im(g_1 - g_2)g_3^*, \qquad (29)\\
d_{55}\frac{d\sigma}{d\Omega} &= \frac{1}{3}Im(g_1 - g_2)(g_3 - g_4)^*, \qquad d_{56}\frac{d\sigma}{d\Omega} = \frac{1}{3}Img_1 g_3^*, \qquad d_{57}\frac{d\sigma}{d\Omega} = -\frac{1}{3}Img_3 g_4^*,\\
d_{51} &= d_{54} = d_{58} = d_{59} = 0.
\end{aligned}
$$

7 Selection of polarization observables for the complete experiment

Selecting vector-tensor combinations for measuring we are proceeding from:

- Measurements of the tensor polarization of secondary deuterons is more difficult in comparison with measurements of vector polarization of secondary particles, especially if one takes into account, that as a rule, the predominant component of such a polarization is longitudinal.
- Vector-tensor combinations of polarization of initial particles, which create polarization of secondary particles, comprising nonvertical components, are not desirable.
- Any direction of the target polarization axis is acceptable, while the beam polarization axis remains vertical.

Here we present the full set of experiments which do not contradict to the formulated principles. For more easy understanding of formulae, mentioned below, we notice here the following properties of the vector $Q_a = Q_{ab}m_a$, where m_a is an arbitrary vector. We assume the quantization axis is the z-axis. The tensor of polarization in this case has the form

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

It is easy to see that $\mathbf{Q}||\mathbf{m}$, if $\mathbf{m}$ is parallel or perpendicular to z-axis, and we have

$$\mathbf{Q}\times\mathbf{m} = 0.$$

For an arbitrary angle β between the direction of $\mathbf{m}$ and z-axis, say, in the xz-plane, we have:

$$\mathbf{Qm} = \frac{Q_{zz}|\mathbf{m}|}{2}(3cos^2\beta - 1), \quad \mathbf{Q}\times\mathbf{m} = (0, \frac{3}{4}Q_{zz}|\mathbf{m}|sin2\beta, 0), \qquad (30)$$

i.e. resulting vector of the vector product is always perpendicular to the plane created by the vector $\mathbf{m}$ and the z-axis.

1. Three of four possible asymmetries of the cross section satisfy to listed above restriction, namely, a_0, a_1 and a_3 (8).
2. The measurement of the polarization of secondary protons, when only initial protons are vertically polarized,

   $$\vec{p} + d \to d + \vec{p},$$

   allows one to find b_{11} (11).

3. The same, but only initial deuterons have a vertical vector polarization,

$$p + \vec{d} \to d + \vec{p},$$

allows one to find b_{21} (12).

4. The case when both initial particles are vector polarized (vertically) does not provide one by additional information.

5. The measurement of a vector polarization of secondary deuterons, when only initial protons are vertically polarized,

$$d + \vec{p} \to p + \vec{d}$$

allows one to find $c_{11} = b_{21}$ (12), i.e. this observable is equivalent to the considered in item 3.

6. The same, but only initial deuterons have a vertical vector polarization,

$$\vec{d} + p \to p + \vec{d}$$

allows one to find c_{21} (18).

7. An unpolarized proton beam, interacting with a tensor polarized deuterium target with a polarization axis lying in the horizontal plane (the most preferable angle respectively the beam direction is 45°), produce secondary protons (and deuterons) with a vertical polarization,

$$p + \vec{d} \to d + \vec{p}.$$

That allows one to find b_{31} (13):

$$|\mathbf{P}_2| = \frac{3}{4} b_{31} Q_{zz} sin2\beta.$$

8. A measurement of vector polarization of deuterons at the initial conditions as in item 7

$$p + \vec{d} \to \vec{d} + p$$

allows one to find c_{31} (19):

$$|\mathbf{S}_2| = \frac{3}{4} c_{31} Q_{zz} sin2\beta.$$

9. A vertical polarization of protons (and deuterons) emerges when initial protons are vertically polarized and initial deuterons have a tensor (vertical or longitudinal) polarization:

$$\vec{p} + \vec{d} \to d + \vec{p}$$

We have

$$|\mathbf{P}_2| = b_{11}|\mathbf{P}| - \left(\frac{b_{51}}{2} - b_{55}\right)|\mathbf{P}|Q_{zz}$$

in case of vertical tensor polarization and

$$|\mathbf{P}_2| = b_{11}|\mathbf{P}| + \left(b_{51} - \frac{b_{55}}{2}\right)|\mathbf{P}|Q_{zz}.$$

in case of longitudinal tensor polarization. Combining results of these two measurements (b_{11} can be determined using the mode of initial states with $Q_{zz} = 0$) one can separate contributions of b_{51} and b_{55} (15).

10. Measuring vector polarization of deuterons at the initial conditions as in item 9

$$\vec{p} + \vec{d} \to \vec{d} + p$$

we have

$$|\mathbf{S}_2| = c_{11}|\mathbf{P}| - \left(\frac{c_{51}}{2} - c_{55}\right)|\mathbf{P}|Q_{zz}$$

in case of vertical tensor polarization and

$$|\mathbf{S}_2| = c_{11}|\mathbf{P}| + \left(c_{51} - \frac{c_{55}}{2}\right)|\mathbf{P}|Q_{zz}.$$

in case of longitudinal tensor polarization to determine c_{51} and c_{55} (21).

Full set of suggested experiments is 13. Fife of them, namely a_0 (8), b_{11} (11), b_{51}, b_{55}(15) and c_{21} (18), allows to find PSF, expressed through modules of scalar amplitudes g_i. PSF a_0 (T_{20}) is already measured in a wide energy range[2, 3, 4]. Since this set is overdetermined, the measurement with longitudinal tensor polarization of the initial deuteron, mentioned in item 9, can be excluded as more difficult. Carrying measurements with only vertical tensor polarization, we deal with the combination $b_{51}/2 - b_{55}$ which is also a function of modules of scalar amplitudes g_i.

Only a part of the rest set of 8 experiments is sufficient to determine completely phase shifts. PSF b_{21} is measured at Saclay[4]. It is desirable to extend the range of initial energies. The experiments, most sensitive to phase shifts, are those connected with T-odd vector-tensor polarization correlation. These are a_3 (8), b_{31} (13) and c_{31} (19). Notice, that in framework of the IA all T-odd asymmetries go to zero. Therefore measurements of such asymmetries will be measurements of power of adequateness of the IA. Notice, that preparation of the initial state when the deuteron has not vertical tensor polarization can be more easy realized when we deal with a proton beam and a deuterium target.

It seems to us, the most interesting energy range to investigate the discussed reaction is that which accords to the deuteron constituents internal momenta range from 0.2 to 1.0 GeV/c. Two kinematically equivalent stages of experiments are possible: 1) a proton beam hits a deuteron target; 2) a deuteron beam hits a proton target. In the first case according primary momentum range is 0.65 – 4.0 GeV/c; then secondary protons go back in the momentum range of 0.2 – 0.53 GeV/c, and secondary deuterons go forward in the momentum range of 0.85 –4.53 GeV/c. In the second case the diapason of initial momenta is 1.3 – 8.0 GeV/c; then secondary deuteron momenta are in range of 0.9 – 6.9 GeV/c, and secondary proton momenta are in range of 0.4 – 1.1 GeV/c, both in forward direction.

When secondary protons are detected, the momentum resolution not less than 0.1% is needed to identify the reaction. This condition is not so strong, when secondary deuterons are detected.

8 The Impulse Approximation

The matrix element corresponding to the ONE mechanism has the form

$$\mathcal{M} = \chi_2^{\dagger}[\vec{\sigma}\mathbf{U}_1 a(s) + (\vec{\sigma}\mathbf{k})(\mathbf{k}\mathbf{U}_1)b(s)] \times [\vec{\sigma}\mathbf{U}_2 a(s) + (\vec{\sigma}\mathbf{k})(\mathbf{k}\mathbf{U}_2)b(s)]\chi_1, \quad (31)$$

where $a(s)$ and $b(s)$ are the following combinations of the S- and D-wave components of the DWF:

$$a(s) = \Psi_s(k(s)) + \frac{1}{\sqrt{2}}\Psi_d(k(s)), \quad b(s) = -\frac{3}{\sqrt{2}}\Psi_d(k(s)), \quad (32)$$

where the internal momentum k is a single-valued function of s, but not the same in different approaches.

Comparing the matrix element (31) with the general structure (1) we find that the amplitudes $g_i(s)$ are related to the DWF components by equations

$$g_1 = g_4 = a^2, \qquad g_2 = c^2, \qquad g_3 = ac, \qquad c = (a+b) = \Psi_s - \sqrt{2}\Psi_d. \tag{33}$$

Then the cross section for unpolarized particles has a form

$$\left(\frac{d\sigma}{d\Omega}\right)_o = \frac{1}{3}(2a^2+c^2)^2 = 3(\Psi_s^2+\Psi_d^2)^2 = 3d^2. \tag{34}$$

The PSF b_{ij}, c_{ij}, d_{ij} are defined by such a way that they depend explicitly on values of a polarization of initial particles. This dependence is determined by factor F, defined in (6). We indicate below in brackets the conditions, when $F = 1$. When we deal with the deuteron tensor polarization in the initial state, this factor cannot be reduced to 1. In these cases we use the explicit form of F which is valid at conditions, listed in brackets. All this is to the point for the separating of "physical parts" of the PSF in general approach.

For the selected experiments (apart from those connected with T-odd effects) we have

$$a_0 = \frac{a^2-c^2}{3d}, \quad a_1 = \frac{ac^3}{3d^2}, \tag{35}$$

$$b_{11} = \frac{1}{F}\frac{c^4}{9d^2}, \quad (Q_{zz}=0,\ \mathbf{S}=0), \tag{36}$$

$$b_{21} = c_{11} = \frac{1}{F}\frac{ac}{d} \quad (Q_{zz}=0,\ \mathbf{P}=0), \tag{37}$$

$$b_{51} = \frac{1}{(1+a_0\mathbf{Qk})}\frac{c^2(a^2-c^2)}{9d^2}, \quad b_{55} = \frac{1}{(1+a_0\mathbf{Qk})}\frac{2a^2c^2}{9d^2}, \tag{38}$$
$$\frac{b_{51}}{2} - b_{55} = -\frac{1}{(1+a_0\mathbf{Qk})}\frac{c^2(3a^2+c^2)}{18d^2} \quad (\mathbf{S}=0),$$

$$c_{21} = \frac{1}{F}\frac{a^2c^2}{d^2} = b_{21}^2 \quad (Q_{zz}=0,\ \mathbf{P}=0), \tag{39}$$

$$c_{51} = \frac{1}{(1+a_0\mathbf{Qk})}\frac{ac(a^2-c^2)}{3d^2}, \quad c_{55}=0 \quad (\mathbf{S}=0). \tag{40}$$

The version of the IA, when the DWF comprises P-wave components, is considered in ref.[5].

9 Conclusion

We showed here that the spin structure of the backward elastic dp scattering is much simpler than in general case for noncollinear kinematics where 12 scalar (complex) amplitudes, depending on two kinematical variables, are needed to describe completely the process.

In our case the complete experiment can be realized using measurements which are not beyond of some restrictions of simplicity. The optimal way of realization of the complete experiment is two steps one. The first step is to measure polarization observables which are sensitive only to modules of scalar amplitudes. And then to measure observables, sensitive to phase shifts between different amplitudes. For this purpose the T-odd polarization observables are most suitable.

The suggested set of experiments is overdetermined. Therefore the choice of the minimal set of experiments is not unique and can be varied dependently on existing experimental possibilities. Here we briefly review the experimental possibilities in the world.

Availability of the polarized deuteron beam and the polarized proton target[18] at the Dubna synchrophasotron allows first of all to carry out the spin correlation experiment (PSF a_1). This project[19] is adopted. The investigation of the internal momenta range from 0.3 to 0.85 GeV/c is assumed. To identify the reaction, secondary deuterons will be detected. If the secondary deuterons spectrometer will be developed up to a polarimeter, measurements of PSF c_{11} and c_{21} will be available.

Good conditions for measurement of c_{21} exist at KEK[20].

At COSY, using a polarized proton beam and a polarized deuteron target at the Zero Degree Facility[21] (ZDF), measurements of PSF a_1 and a_3 is feasible[7]. The energy range is roughly the same as in Dubna. If the backward spectrometer of the ZDF will be developed up to a polarimeter, than measurements of PSF b_{11}, b_{21}, b_{31}, b_{51}, and b_{55} becomes feasible.

A wide program of realization of the complete experiment can be developed at AGS, RHIC and LISS.

The authors thank to A.M.Baldin and F.Lehar for strong support of this activity, C.F.Perdrisat and V.Punjabi for their efforts in the direction of realization of the complete experiment. We also grateful to J.Arvieux, L.S.Azhgirey, S.Belostotsky, A.Boudard, P.D.Eversheim, V.I.Komarov, L.V.Malinina, 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.

References

[1] P.Berthet et al., J.Phys.G.: Nucl.Phys. **8** (1982) 111.

[2] J.Arvieux et al., Nucl. Phys. **A431** (1984) 6132.

[3] L.S.Azhgirey et al., in: AIP Conference Proceedings 334, Few-Body Problems in Physics, Williamsburg VA, ed. by F.Gross, (1994) 415, submitted to Phys.Lett.

[4] V.Punjabi et al., Phys. Lett. **B 350** (1995) 178.

[5] I.M.Sitnik, V.P.Ladygin and M.P.Rekalo, Yad. Fiz. **57** (1994) 1270 [transl. Phys. of Atomic Nucl. **57** (1994) 2089].

[6] J.Carbonell, V.A.Karmanov, Nucl. Phys. **A581** (1994) 625.

[7] M.P.Rekalo, I.M.Sitnik, Phys. Lett. **B356** (1995) 434.

[8] V.N.Gribov, JETP **43** (1962) 1529; M.P.Rekalo, JETP **45** (1963) 595; V.N.Gribov, L.Okun and I.Pomeranchuk, JETP **45** (1963) 1114. M.P.Rekalo, V.G.Gorshkov, G.V.Frolov, JETP **45** (1963) 285 and 672.

[9] W.W.Buck and F.Gross, Phys. Rev. **D 20** (1979) 2361.

[10] L.Ya.Glozman, V.G.Neudatchin and I.T.Obukhovsky, Phys. Rev. **C 48** (1993) 389.

[11] S.S.Vasan, Phys. Rev. **D 8** (1973) 4092.

[12] A.P.Kobushkin, A.I.Syamtomov, C.F.Perdrisat, V.Punjabi, Phys. Rev. **C 50** (1994) 2627.

[13] M.Tanifuji, Phys. Lett. **B363** (1995) 151.

[14] G.G.Ohlsen, Rep. Prog. Phys. **35** (1972) 717.

[15] V.Ghazikhanian et al., Phys. Rev. **C43** (1991) 1532.

[16] E.Conzett, Phys. Rev. **C48** (1993) 423.

[17] P.D.Eversheim et al., COSY prposal #3.

[18] F.Lehar et al., NIM **A356** (1995) 58.

[19] I.M.Sitnik et al., JINR Rapid Com. No.2[70]-95.

[20] C.F.Perdrisat et al., Letter of intent for KEK.

[21] S.V.Dzhemuchadze et al., in *Proc. of Int. Symp. "Dubna Deuteron-93"* Dubna, Russia, Sept. 14-18, JINR E2-94-95 (1994) p.61; S.V.Dzhemuchadze et al., COSY Proposal No. 20, IKP KFA, Julich, 1992.

Received by Publishing Department
on September 10, 1996.