E2-2008-62

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# THE RATIO $R_{dp}$ OF THE QUASI-ELASTIC $nd \to p(nn)$ TO THE ELASTIC $np \to pn$ CHARGE-EXCHANGE PROCESS YIELDS AT $0^\circ$ OVER $0.55-2.0$ GeV NEUTRON BEAM ENERGY REGION: 2. COMPARISON OF THE RESULTS WITH THE MODEL DEPENDENT CALCULATIONS

Submitted to «Yadernaya Fizika»

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Отношение $R_{dp}$ выходов процессов квазиупругой $nd \to p(nn)$ и упругой $np \to pn$ перезарядки под углом $0^\circ$ в области энергий пучка нейтронов 0,55–2,0 ГэВ.
2. Сравнение результатов с модельно-зависимыми расчетами

В нашей предыдущей статье были представлены новые экспериментальные результаты по отношению $R_{dp}$ выхода $nd \to pnn$ реакции квазиупругой перезарядки под углом $0^\circ$ к выходу упругой $np \to pn$ перезарядки. Измерения проводились на нуклотроне ЛВЭ ОИЯИ при значениях кинетической энергии пучка нейтронов 0,55, 0,8, 1,0, 1,2, 1,4, 1,8 и 2,0 ГэВ. В настоящей статье проведено сравнение этих данных с расчетными значениями $R_{dp}$, полученными в рамках импульсного приближения с использованием наборов инвариантных $NN$ амплитуд из решений GW/VPI фазового анализа. Расчетные значения $R_{dp}$, выполненные с набором инвариантных амплитуд для упругой $np \to pn$ перезарядки при $\theta_{p,\mathrm{CM}} = 0^\circ$, хорошо согласуются с экспериментальными данными. Это подтверждает, что при $\theta_{p,\mathrm{CM}} = 0^\circ$ процесс $nd \to pnn$ обусловлен реакцией упругой $np \to pn$ перезарядки. Таким образом, показано, что полученные экспериментальные $R_{dp}$ результаты могут быть использованы в экспериментальной программе проекта «Дельта–Сигма» для уменьшения неопределенностей при извлечении реальных частей амплитуд рассеяния.

Работа выполнена в Лаборатории высоких энергий им. В. И. Векслера и А. М. Балдина ОИЯИ.

Препринт Объединенного института ядерных исследований. Дубна, 2008

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The Ratio $R_{dp}$ of the Quasi-Elastic $nd \to p(nn)$ to the Elastic $np \to pn$ Charge-Exchange Process Yields at $0^\circ$ over 0.55–2.0 GeV Neutron Beam Energy Region:
2. Comparison of the Results with the Model Dependent Calculations

In our previous paper, the new experimental results on ratio $R_{dp}$ of the quasi-elastic charge-exchange yield at $0^\circ_{\mathrm{Lab}}$ for the $nd \to p + (nn)$ reaction to the elastic $np \to pn$ charge-exchange yield, were presented. The measurements were carried out at the Nuclotron of the Veksler and Baldin Laboratory of High Energies of the Joint Institute for Nuclear Research at the neutron beam kinetic energies of 0.55, 0.8, 1.0, 1.2, 1.4, 1.8 and 2.0 GeV. In this paper, the comparison of these $R_{dp}$ data with the $R_{dp}$ calculations obtained within the impulse approximation by using the invariant amplitude sets from the GW/VPI phase-shift analysis, is made. The calculated $R_{dp}$ values with the set of invariant amplitude data for the elastic $np \to pn$ charge exchange at $\theta_{p,\mathrm{CM}} = 0^\circ$ are in a good agreement with the experimental data. It has been confirmed that at $\theta_{p,\mathrm{CM}} = 0^\circ$ the $nd \to pnn$ process is caused by the elastic $np \to pn$ charge-exchange reaction. Thus, it has been shown that the obtained experimental $R_{dp}$ results can be used for the Delta-Sigma experimental programme to reduce the total ambiguity in the extraction of the amplitude real parts.

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

Preprint of the Joint Institute for Nuclear Research. Dubna, 2008

## INTRODUCTION

In our previous paper [1], the new experimental results on ratio $R_{dp}$ of the quasi-elastic charge-exchange yield at $0^{\circ}_{\rm Lab}$ for the $nd \to p + (nn)$ reaction to the elastic $np \to pn$ charge-exchange yield, were presented. The measurements were carried out at the Nuclotron of the Veksler and Baldin Laboratory of High Energies of the Joint Institute for Nuclear Research at the neutron beam kinetic energies of $0.55, 0.8, 1.0, 1.2, 1.4, 1.8$ and 2.0 GeV. The intense quasi-monochromatic neutron beam was produced by break-up of accelerated and extracted to experimental hall deuterons. In both reactions mentioned above the outgoing protons with momenta $\mathbf{p_p}$ near to the neutron beam momentum $\mathbf{p_{n,beam}}$ were detected in the directions close to the direction of incident neutrons, i.e., in the vicinity of the scattering angle $\theta_{p,\rm Lab} = 0^{\circ}$. Thus, we consider such an outgoing proton as the former beam neutron which was scattered at $\theta_{p,\rm CM} = 0^{\circ}$ and got the electric charge in the charge-exchange process. We use this definition everywhere in this paper.

Measured in the same data taking runs, the above charge-exchange angular distributions were corrected for the well-known instrumental effects and averaged in the vicinity of the incident neutron beam direction. These two corrected angular distributions are proportional to the differential cross sections of the two relevant reactions.

In this paper, the comparison of these $R_{dp}$ data with the $R_{dp}$ calculations obtained within the impulse approximation by using the invariant amplitude sets from the GW/VPI phase-shift analysis, is made.

The work was performed within the programme of the JINR project «Delta-Sigma experiment» [2–4] (see also Ref. [30] in arXiv:0706.2195 [nucl-th]). The aim of this experimental programme is to determine the imaginary and real parts of the $np \to np$ forward ($\theta_{n,\rm CM} = 0$) and backward ($\theta_{n,\rm CM} = \pi$) all elastic scattering amplitudes over the 1.2–3.7 GeV energy region. In this highest energy interval of free polarized neutron beams the measurements are possible at the Nuclotron only.

At the forward and backward angles only three complex amplitudes are independent. The scattering amplitudes in the forward and backward hemispheres are determined by the angular symmetry conditions: they differ for isospins $I = 1$ and $I = 0$. We assume that the $I = 1$ amplitudes are known. Consequently, for the direct reconstruction of the $np$ amplitudes, altogether, at least, six independent observables at either the forward or backward directions, are needed. Two

$np$ observables are well known, one of them is the spin independent $np$ total cross section $\sigma_{0\mathrm{tot}}$, the second one is the $np \to np$ differential cross section at $\theta_{n,\mathrm{CM}} = \pi$.

The research programme «Delta-Sigma» foresees the measurements of total cross section differences $\Delta\sigma_{L,T}(np)$ and spin correlation parameters $A_{00kk}(np \to np)$ and $A_{00nn}(np \to np)$ at $\theta_{n,\mathrm{CM}} = \pi$ for the longitudinal ($L$) and transverse ($T$) beam and target polarization directions, respectively. The $\Delta\sigma_{L,T}(np)$ observables together with $\sigma_{0\mathrm{tot}}$ are linearly related to the imaginary part of the independent forward scattering amplitudes via optical theorems. These three observables unambiguously determine the imaginary parts of all the amplitudes.

The $\Delta\sigma_{L,T}(np)$ observables are to be measured in transmission experiments. Measurements of the $-\Delta\sigma_L(np)$ energy dependence were carried out at ten different values of energy [5–10]. The $L$-polarized neutron beam from the Synchrophasotron of the JINR VBLHE and the Dubna $L$-polarized proton target were used. New measurements of the $\Delta\sigma_{L,T}(np)$ are expected after the new high-intensity source of polarized deuterons is operational at the Nuclotron.

The $A_{00kk}(np \to np)$ and $A_{00nn}(np \to np)$ values are to be defined in the backward direction. These observables could be measured simultaneously with the corresponding $\Delta\sigma_{L,T}(np \to np)$ experiments. Using the imaginary parts of the forward amplitudes transformed into the backward direction, the $np$ differential cross section and the two spin correlations at $\theta_{\mathrm{CM}} = \pi$ are sufficient to obtain the three real parts of the amplitudes. In contrast to the optical theorems at $\theta = 0°$, the scattering amplitudes in the backward direction are related to the scattering observables by bilinear equations. Each of them may have, in principle, an independent ambiguity in the sign. The total ambiguity is then eight-fold at most and any independent experiment decreases it by the factor of two. To reduce the total ambiguity in the scattering amplitude determination, the «Delta-Sigma» collaboration performed the measurements of the ratio $R_{dp} = (d\sigma/d\Omega)(nd)/(d\sigma/d\Omega)(np)$ for the charge exchange processes on the deuterium and hydrogen targets. The knowledge of $R_{dp}$ value could provide one additional constraint and reduce the ambiguity discussed above.

Section 1 gives a brief determination of the $R_{dp}$ observable. Sections 2 is devoted to the $R_{dp}$ calculation procedure and discussion of the results of the comparison of the calculated $R_{dp}$ values with the experimental ones. Conclusions are given at the end of the paper.

## 1. DETERMINATION OF THE $R_{dp}$ OBSERVABLE

Throughout this paper we have used the nucleon–nucleon ($NN$) formalism, notations of elastic $NN$ scattering observables and the invariant scattering amplitude representation from [11].

As mentioned above, the observable $R_{dp}$ is the ratio of the quasi-elastic $nd \to p + nn$ (labeled by $nd$) charge-exchange differential cross section at $\theta_{p,\mathrm{CM}} = 0^\circ$ to the free $np \to pn$ (labeled by $np$) elastic one:

$$R_{dp}(\theta) = \frac{(d\sigma/d\Omega)(nd)}{(d\sigma/d\Omega)(np)}. \tag{1.1}$$

In both $nd \to p+nn$ and $np \to pn$ reactions the outgoing (scattered) protons with the momenta $\mathbf{p_p}$ near to the neutron beam momentum $\mathbf{p_{n,beam}}$ were detected in the directions close to the direction of incident neutrons, i.e., in the vicinity of the scattering angle $\theta_{p,\mathrm{Lab}} = 0^\circ$. Thus, we consider such an outgoing proton as the former beam neutron which was scattered at $\theta_{p,\mathrm{CM}} = 0^\circ$ and got the electric charge in the charge-exchange process.

For the purposes of our experimental research programme, it is important to know the relation between the $R_{dp}$ observable and the spin-dependent $NN$ amplitudes.

The differential cross section $(d\sigma/d\Omega)(np)$ can be splitted into the «spin-independent» $(SI)$ and «spin-dependent» $(SD)$ parts:

$$(d\sigma/d\Omega)(np) = (d\sigma/d\Omega)^{SI}(np) + (d\sigma/d\Omega)^{SD}(np). \tag{1.2}$$

Following the theory developed in [12–17], the differential cross section for $nd \to p + (nn)$ reaction within the impulse approximation, can be written as follows:

$$(d\sigma/d\Omega)(nd \to p + nn) = [1 - F(t)](d\sigma/d\Omega)^{SI}(np \to pn) + \\ + [1 - (1/3)F(t)](d\sigma/d\Omega)^{SD}(np \to pn). \tag{1.3}$$

Here $F(t)$ is the deuteron form-factor, which is equal to 1 at the four-momentum transfer $t = (P_n - P_p)^2 = 0$ when the quasi-elastic charge-exchange scattering angle $\theta_p = 0^\circ$. ($P_{n(p)}$ is the 4-momentum of the corresponding particle). The first term on the right-hand side of (1.3) vanishes and for the differential cross section at $\theta_p = 0^\circ$ the theory gives the following expression:

$$(d\sigma/d\Omega)(nd \to p + nn) = (2/3)(d\sigma/d\Omega)^{SD}(np \to pn). \tag{1.4}$$

Using Eqs. (1.2) and (1.4), $R_{dp}$ is related to $np \to pn$ observables by the formula:

$$R_{dp}(\theta_p = 0^\circ) = \frac{(d\sigma/d\Omega)(nd \to p + nn)}{(d\sigma/d\Omega)(np \to pn)} = \frac{2}{3} \cdot \frac{(d\sigma/d\Omega)^{SD}(np \to pn)}{(d\sigma/d\Omega)(np \to pn)}. \tag{1.5}$$

The $NN$ elastic scattering matrix in the invariant amplitude representation [11] is written in the following form:

$$M(\mathbf{k_f}, \mathbf{k_i}) = \frac{1}{2}\Big[(a+b) + (a-b)(\boldsymbol{\sigma}_1, \mathbf{n})(\boldsymbol{\sigma}_2, \mathbf{n}) + (c+d)(\boldsymbol{\sigma}_1, \mathbf{m})(\boldsymbol{\sigma}_2, \mathbf{m}) + \\ + (c-d)(\boldsymbol{\sigma}_1, \mathbf{l})(\boldsymbol{\sigma}_2, \mathbf{l}) + e(\boldsymbol{\sigma}_1 + \boldsymbol{\sigma}_2, \mathbf{n})\Big], \quad (1.6)$$

where $a$, $b$, $c$, $d$ and $e$ are five complex scattering amplitudes which are functions of energy and scattering angle $\theta_{\rm CM}$. $\boldsymbol{\sigma_1}$ and $\boldsymbol{\sigma_2}$ are the Pauli $2 \times 2$ matrices for the beam and target particles, $\mathbf{k_i}$ and $\mathbf{k_f}$ are the unit vectors in the direction of the incident and scattered particles, respectively, and

$$\mathbf{n} = \frac{\mathbf{k_i} \times \mathbf{k_f}}{|\mathbf{k_i} \times \mathbf{k_f}|}, \quad \mathbf{l} = \frac{\mathbf{k_f} + \mathbf{k_i}}{|\mathbf{k_f} + \mathbf{k_i}|}, \quad \mathbf{m} = \frac{\mathbf{k_f} - \mathbf{k_i}}{|\mathbf{k_f} - \mathbf{k_i}|}. \quad (1.7)$$

The term $(a+b)$ in Eq. (1.6) is spin-independent $(SI)$ and all the other terms are spin-dependent $(SD)$.

The scattering matrices for $pp$, $nn$, $np$, and $pn$ interactions are given in terms of the isosinglet ($M_0$) and isotriplet ($M_1$) matrices, both of the form Eq. (1.6). Putting

$$M(\mathbf{k_f}, \mathbf{k_i}) = \frac{M_0}{4}[1 - (\boldsymbol{\tau}_1, \boldsymbol{\tau}_2)] + \frac{M_1}{4}[3 + (\boldsymbol{\tau}_1, \boldsymbol{\tau}_2)], \quad (1.8)$$

where $\boldsymbol{\tau}_1$ and $\boldsymbol{\tau}_2$ are the nucleon isospin matrices, one obtains

$$M(pp \to pp) = M(nn \to nn) = M_1, \quad (1.9a)$$

$$M(np \to np) = M(pn \to pn) = \frac{1}{2}(M_1 + M_0), \quad (1.9b)$$

$$M(np \to pn) = M(pn \to np) = \frac{1}{2}(M_1 - M_0). \quad (1.9c)$$

Equations (1.9) are also valid for individual scattering amplitudes independently of their representation.

It is important to remember that Eqs. (1.6)–(1.9c) are valid for any allowed fixed values of the total energy of the interacting particles $E_{\rm tot,CM}$ and scattering angle $\theta_{\rm CM}$. The symmetry conditions shown in Table 1 provide the mutual relation between the elastic scattering amplitudes $a$ to $e$ in Eq. (1.6) at $\theta_{\rm CM}$ and at $\pi - \theta_{\rm CM}$ for the given pure isospin states $I = 0$ and $I = 1$ [11].

The $np$ elastic scattering differential cross section is given in [11]:

$$\frac{d\sigma}{d\Omega} = \frac{1}{2}\Big(|a|^2 + |b|^2 + |c|^2 + |d|^2 + |e|^2\Big). \quad (1.10)$$

In the forward and backward directions $e = 0$. The spin-dependent $(SD)$ part of the differential cross section can be obtained by subtraction of the $SI$ part

**Table 1. Symmetry properties of the $NN$ scattering amplitudes**

| $I=0$ amplitudes | $I=1$ amplitudes |
|---|---|
| $a_0(\theta)=+a_0(\pi-\theta)$ | $a_1(\theta)=-a_1(\pi-\theta)$ |
| $b_0(\theta)=+c_0(\pi-\theta)$ | $b_1(\theta)=-c_1(\pi-\theta)$ |
| $c_0(\theta)=+b_0(\pi-\theta)$ | $c_1(\theta)=-b_1(\pi-\theta)$ |
| $d_0(\theta)=-d_0(\pi-\theta)$ | $d_1(\theta)=+d_1(\pi-\theta)$ |
| $e_0(\theta)=-e_0(\pi-\theta)$ | $e_1(\theta)=+e_1(\pi-\theta)$ |

$(d\sigma/d\Omega)^{SI}=|a+b|^2/4$ from Eq. (1.10). The following formula relates $R_{dp}(0^\circ)$ with the invariant amplitudes [18]:

$$R_{dp}(\theta_{p,\mathrm{CM}}=0^\circ)=\frac{2}{3}\cdot\frac{\frac{1}{4}|a-b|^2+\frac{1}{2}\Big(|c|^2+|d|^2\Big)}{\frac{1}{2}\Big(|a|^2+|b|^2+|c|^2+|d|^2\Big)}. \qquad (1.11)$$

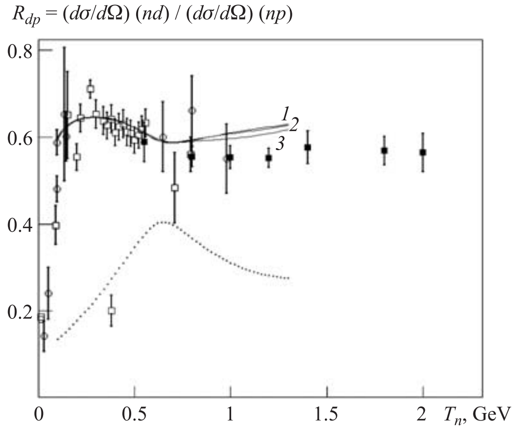
## 2. PROCEDURE OF THE $R_{dp}$ CALCULATION, COMPARISON WITH THE EXPERIMENT AND DISCUSSIONS

The $R_{dp}$ results [1] are presented in Table 2 as well as in the figure. The total $R_{dp}$ error for each energy is the square root of the sum of the statistical and systematic errors squared.

**Table 2. Values of $R_{dp}=d\sigma/d\Omega(nd\to pnn)/d\sigma/d\Omega(np\to pn)$ at $\theta_{p,\mathrm{Lab}}=0^\circ$ [1]. Total error for each energy is the square root of the sum of the statistical and systematic errors squared**

| $NN$ | $T_n$, GeV | $P_n$, GeV/$c$ | $R_{dp}$ | Errors | | |
|---|---|---|---|---|---|---|
| | | | | Stat. | Syst. | Total |
| 1 | 0.55 | 1.156 | 0.589 | 0.024 | 0.039 | 0.046 |
| 2 | 0.80 | 1.464 | 0.554 | 0.017 | 0.016 | 0.023 |
| 3 | 1.00 | 1.697 | 0.553 | 0.011 | 0.023 | 0.026 |
| 4 | 1.20 | 1.922 | 0.551 | 0.011 | 0.019 | 0.022 |
| 5 | 1.40 | 2.143 | 0.576 | 0.028 | 0.026 | 0.038 |
| 6 | 1.80 | 2.573 | 0.568 | 0.016 | 0.029 | 0.033 |
| 7 | 2.00 | 2.785 | 0.564 | 0.014 | 0.042 | 0.045 |

The $R_{dp}$ results [1] are close to 0.56 and remain nearly constant with the energy over the investigated energy region. The earlier obtained $R_{dp}$ results [19–33] (collected in [18]), are also plotted in the figure. The $R_{dp}$ value [34] at $T_n=0.98$ GeV, obtained recently on the Dubna hydrogen bubble chamber data




The energy dependence for the $R_{dp}$ results. Black squares — for our experiment [1], open squares and circles — for the existing data at lower energy from compilation [18]. The $R_{dp}$ value at $T_n = 0.98$ GeV was taken from [33]. The curves represent the energy behaviour of $R_{dp}$ calculated by formula (1.11) using $NN$ invariant amplitude data sets from the energy-dependent phase-shift analyses [35–37]. The solid curves are the calculations with the amplitude data sets for the elastic $np \to pn$ charge exchange at $\theta_{p,\mathrm{CM}} = 0^\circ$. The dotted curve represents the $R_{dp}$ values with the amplitudes data set for the elastic $np \to np$ scattering at $\theta_{n,\mathrm{CM}} = \pi$

for $dp \to (pp)n$ reaction, is also shown in the figure. All these data were measured below 1 GeV.

The $R_{dp}$ values were estimated on formula (1.11) using the invariant amplitude data sets for the elastic $np \to np$ (Amp$\,(np)$) and $pp \to pp$ (Amp$\,(pp) =$ Amp$\,(I = 1)$) scattering at $\theta_{n,\mathrm{CM}} = \pi$ and $\theta_{p,\mathrm{CM}} = \pi$. The amplitude data sets were received from I. I. Strakovsky for the GW/VPI phase-shift analysis (PSA) solutions: SM97 [35], SP00 [36] and SP07 [37].

The amplitudes Amp$\,(np)$ are the mixture of the pure isospin ($I = 1$ and $I = 0$) state amplitudes according to Eq. (1.9b)

$$\mathrm{Amp}\,(np) = \frac{1}{2}[\mathrm{Amp}\,(I = 1) + \mathrm{Amp}\,(I = 0)] \qquad (2.1)$$

and

$$\mathrm{Amp}\,(I = 0) = 2\mathrm{Amp}\,(np) - \mathrm{Amp}\,(I = 1). \qquad (2.2)$$

Using the existing Amp$\,(np)$ and Amp$\,(I = 1)$ sets, one can obtain the Amp$\,(I = 0)$ set by Eq. (2.2). Thus, we have the complete set of the pure isospin invariant amplitudes for the elastic $np \to np$ scattering at $\theta_{n,\mathrm{CM}} = \pi$:

$$\mathrm{Amp}\,(np \to np, \theta_{n,\mathrm{CM}} = \pi) = \frac{1}{2}[\mathrm{Amp}\,(I = 1) + \mathrm{Amp}\,(I = 0)]. \tag{2.3}$$

Let us try to calculate the $R_{dp}$ values by Eq. (1.11) for the elastic $np \to np$ scattering at $\theta_{n,\mathrm{CM}} = \pi$ using either immediately Amp $(np)$ isospin mixed amplitude set or the obtained from Eq. (2.3) $\frac{1}{2}[\mathrm{Amp}(I = 1) + \mathrm{Amp}(I = 0)]$ amplitude set. The dotted curve in the figure represents the energy behaviour of $R_{dp}$ calculated with these data sets from the energy dependent PSA solution [37]. (Calculations with the data set for any of the SM97, SP00 or SP07 solutions have given almost the same results). The results of these calculations disagree with the obtained experimental $R_{dp}$ data.

To obtain the necessary amplitude set for the elastic $np \to pn$ charge exchange at $\theta_{p,\mathrm{CM}} = 0°$, one needs at first according to Table 1 [11], to perform the angular $\theta_{n,\mathrm{CM}} \to \pi - \theta_{n,\mathrm{CM}}$ transformations of the above-obtained Amp $(I = 1)$ and Amp $(I = 0)$ sets for the elastic $np \to np$ scattering at $\theta_{n,\mathrm{CM}} = \pi$. Thus, we obtain the angular transformed $I = 0$ and $I = 1$ amplitude sets for the elastic $np \to np$ scattering at $\theta_{n,\mathrm{CM}} = 0°$:

$$\begin{aligned}\mathrm{Amp}\,(np \to np, \theta_{n,\mathrm{CM}} = 0) &= \\ &= \frac{1}{2}[\mathrm{Amp}_{\mathrm{transf}}(I = 1) + \mathrm{Amp}_{\mathrm{transf}}(I = 0)]. \end{aligned} \tag{2.4}$$

In this way we have performed the $\mathbf{k}_{\mathbf{n},\mathbf{f}} \to -\mathbf{k}_{\mathbf{n},\mathbf{f}}$ transformation which changed the basis vectors orientation

$$\mathbf{n} \to -\mathbf{n}, \quad \mathbf{l} \to -\mathbf{m}, \quad \mathbf{m} \to -\mathbf{l}. \tag{2.5}$$

For the second step, one needs according to Eq. (1.9c), which corresponds to the permutation of the final state nucleons $n_f \to p_f$, to take the half-difference of the angular transformed $I = 1$ and $I = 0$ amplitudes. Thus, the necessary amplitude set for the elastic $np \to pn$ charge exchange at $\theta_{p,\mathrm{CM}} = 0°$ is the following:

$$\mathrm{Amp}(np \to pn, \theta_{p,\mathrm{CM}} = 0) = \frac{1}{2}[\mathrm{Amp}_{\mathrm{transf}}(I = 1) - \mathrm{Amp}_{\mathrm{transf}}(I = 0)]. \tag{2.6}$$

The $R_{dp}$ values for the elastic $np \to pn$ charge exchange at $\theta_{p,\mathrm{CM}} = 0°$ were obtained by Eq. (1.11) using the (2.6) amplitude set. The solid curves in the figure show the energy behaviour of $R_{dp}$ calculated with the transformed amplitude sets for the energy dependent PSA solution [35–37]. The calculated $R_{dp}$ values with the set of invariant amplitude data for the elastic $np \to pn$ charge exchange at $\theta_{p,\mathrm{CM}} = 0°$ are in a good agreement with the experimental data.

The influence of a final state interaction (FSI) of the two remaining nucleons on the $nd \to p(nn)$ reactions differential cross section has been recently studied by N. B. Ladygina [38]. She has shown that the FSI influence on the ratio $R_{dp}$ is small (about $10\%$ at $T_n = 0.8$ GeV) and decreases with the $T_n$ increasing.

It has been confirmed that at $\theta_{p,\mathrm{CM}} = 0^\circ$ the $nd \to pnn$ process is caused by the spin-dependent amplitudes of the elastic $np \to pn$ charge-exchange reaction.

## CONCLUSIONS

The $R_{dp}$ values have been estimated in frame of impulse approximation by formula (1.11) using the invariant amplitude data sets for the elastic $np \to np$ and $pp \to pp$ scattering at $\theta_{n,\mathrm{CM}} = \pi$ and $\theta_{p,\mathrm{CM}} = \pi$. The calculated $R_{dp}$ values with the set of invariant amplitude data for the elastic $np \to np$ scattering at $\theta_{n,\mathrm{CM}} = \pi$ disagree with the $R_{dp}$ experimental data. On the other hand, the calculated $R_{dp}$ values with the set of invariant amplitude data for the elastic $np \to pn$ charge exchange at $\theta_{p,\mathrm{CM}} = 0^\circ$ are in a good agreement with the experimental data. It has been confirmed that at $\theta_{p,\mathrm{CM}} = 0^\circ$ the $nd \to pnn$ process is caused by the spin-dependent amplitudes of the elastic $np \to pn$ charge-exchange reaction.

Thus, it has been shown that the obtained experimental $R_{dp}$ results can be used for the «Delta-Sigma» experimental programme to reduce the total ambiguity in the extraction of the amplitude real parts.

**Acknowledgements.** We would like to thank I. I. Strakovsky who was always ready to help us with some unusual SAID procedures and for the useful discussions. The C. Wilkin's personal support was favorable for our experiment. We also thank N. B. Ladygina for her results concerning the numerical estimation of FSI contributions and her interest to our experiment. The authors thank the JINR, JINR VBLHE and DLNP Directorates for permanent attention and interest to these investigations. The work was in part supported by the Russian Foundation for Basic Research through Grant RFBR-07-02-01025.

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Received on April 30, 2008.

Редактор *В. В. Булатова*

Подписано в печать 17.07.2008.
Формат 60 × 90/16. Бумага офсетная. Печать офсетная.
Усл. печ. л. 0,93. Уч.-изд. л. 1,32. Тираж 420 экз. Заказ № 56249.

Издательский отдел Объединенного института ядерных исследований
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