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STUDY OF $\pi d - \pi' NN$ REACTIONS IN THE (3.3) RESONANCE REGION WITHIN THE THREE-BODY QUASIPOTENTIAL APPROACH

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Емельяненко Г.А. и др. **E4 - 12320**

Исследование $\pi d \to \pi' NN$ реакции в области (3.3) резонанса на основе трехчастичного квазипотенциального подхода

Проведено исследование процессов рассеяния пионов на дейтроне с развалом дейтрона и перезарядкой в области (3.3) резонанса на основе трехчастичного квазипотенциального подхода, успешно использованного ранее авторами для описания упругого πd -рассеяния. В приближении однократного πN-рассеяния, с учетом нуклон-нуклонного взаимодействия в конечном состоянии, рассчитаны интегральное и дифференциальное сечение развала дейтрона пионом и перезарядки. Показано, что эффект NN-взаимодействия в конечном состоянии дает существенный вклад в сечения, но вместе с тем результаты расчетов мало зависят от внеэнергетического поведения t матриц NN-взаимодействия. Разность между полным сечением и суммой упругого и неупругого сечения πd-рассеяния составляет примерно 30% от полного сечения. Теоретические расчеты качественно описывают имеющиеся экспериментальные данные. Предложен новый способ расчета логарифмической сингулярности в трехчастичных уравнениях для непрерывного спектра. Обсуждаются причины расхождения теоретических расчетов с экспериментальными данными.

Работа выполнена в Лаборатории теоретической физики ОИЯИ.

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Emelyanenko G.A. et al. **E4 - 12320**

Study of $\pi d \to \pi' NN$ Reactions in the (3.3) Resonance Region within the Three-Body Quasipotential Approach

The πd -scattering processes with deuteron desintegration and charge exchange in the (3.3) resonance region are investigated in the framework of the three-body quasipotential approach [2], successfully used before [1] for the πd elastic scattering. The differential and integral cross sections for the deuteron break-up and charge exchange reactions, and the momentum distribution of the scattered pions are calculated in the single πN- scattering approximation with taking into account the NN-final state interaction. It is shown that: 1) the NN-final state interaction gives an important contribution to the cross sections, but the results of calculations show a small dependence on the off shell behaviour of the NN collision matrix; 2) the difference between the total cross section and the sum of the elastic and nonelastic πd - scattering cross sections amounts about 30% of the total cross section; 3) the present theory gives only the qualitative description of the available experimental data for the differential cross sections. The reasons for this discrepancy are discussed. A new procedure for handling with the logarithmic singularity is suggested.

The investigation has been performed at the Laboratory of Theoretical Physics, JINR.

Communication of the Joint Institute for Nuclear Research. Dubna 1979

1. INTRODUCTION

In the previous paper [1] we have considered the elastic πd -scattering channel in the (3.3) resonance region on the basis of three-body quasipotential equations obtained in ref. [2]. This approach allows us to study the channels with the three-particle final states. As to the account of the genuine pion absorption channel, it goes out of the framework of the Faddeev-type equations. However, by using the experimental pion absorption cross section (which amounts no more than 7% of the total cross section) and the calculated cross sections of the $\pi d \to \pi' NN$ channels we can get an information on the influence of the absorption channel or others. Besides, the study of the three-particle channels allows us to explore the role of the NN -final state interaction. The characteristics of these channels should clearly be more sensitive to the off-shell behaviour of the NN -collision matrix than the elastic πd -scattering channel.

In the present paper we consider the πd -scattering with the deuteron desintegration and charge exchange processes in the (3.3) resonance region.

2. THE $\pi d \to \pi' NN$ REACTION AMPLITUDE

The antisymmetrized operator for the processes studied $\mathcal{P}_{23} U_{01} \mathcal{P}_{23}$ has the form

$$\mathcal{P}_{23} U_{01} \mathcal{P}_{23} = G_0^{-1} \mathcal{P}_{23} + \mathcal{P}_{23} T_1 G_0 \mathcal{P}_{23} U_{11} \mathcal{P}_{23} + \mathcal{P}_{23} T_2 G_0 U_{2+3,1} \mathcal{P}_{23}, \quad (1)$$

where the antisymmetrized operator for elastic scattering $\mathcal{P}_{23}U_{11}\mathcal{P}_{23}$ and auxiliary operator $U_{2+3,1}\mathcal{P}_{23}$ satisfy the following system of equations

$$\mathcal{P}_{23}U_{11}\mathcal{P}_{23} = \mathcal{P}_{23}T_2 G_0 U_{2+3,1}\mathcal{P}_{23}$$

$$U_{2+3,1}\mathcal{P}_{23} = 2G_0^{-1}\mathcal{P}_{23} + 2T_1 G_0 \mathcal{P}_{23}U_{11}\mathcal{P}_{23} - P_{23}T_2 G_0 U_{2+3,1}\mathcal{P}_{23}. \quad (2)$$

In (1) and (2) P_{23} is the permutation operator of particles 2 and 3 (nucleons), $\mathcal{P}_{23}=\frac{1}{2}(1-P_{23})$ is the antisymmetrization operator, G_0 is the three-body free Green-function, T_1 and T_2 are the NN and πN collision matrices.

It is easy to see that the amplitude of the processes studied $\pi d\to\pi' NN$ has a form (for the sake of convenience spin-isospin quantum numbers are omitted)

$$T_{01}(\vec{q}\,'_{23}\vec{q}\,'_1;\vec{q}_1 P_0) = \sqrt{2}\langle\vec{q}\,'_{23}\vec{q}\,'_1|\mathcal{P}_{23}U_{01}(P_0)\mathcal{P}_{23}|\phi_d\vec{q}_1\rangle \quad (3a)$$

$$= \langle\Psi^{(-)}_{\vec{q}\,'_{23}}\vec{q}\,'_1|\mathcal{P}_{23}U_{11}(P_0)\mathcal{P}_{23}|\phi_d\vec{q}_1\rangle, \quad (3b)$$

where ϕ_d and $\Psi^{(-)}_{\vec{q}\,'_{23}}$ are the wave functions of NN system for the bound and scattering states, P_0 is the energy for the three-body system in c.m.f., $\vec{q}_1$ is the incident pion momentum which coincides with the corresponding Jacobi coordinates in the three-body c.m.s., $\vec{q}_{23}$ is the two-nucleon relative momentum in their c.m.s. For further discussions we need the expression of the matrix element (3b) in the approximation $U_{11}\simeq U_{11}^{(1)}=2T_2$. With the relativistic pion kinematics and in the nonrelativistic limit of nucleons in this approximation we have

$$T_{01}^{(1)}(\vec{q}\,'_{23}\vec{q}\,'_1;\vec{q}_1 P_0) = 2\int\Psi^{(-)}_{\vec{q}\,'_{23}}(\vec{q}\,''_{23})\sqrt{\frac{\omega_1(\vec{q}\,'_{31})}{\omega_1(\vec{q}\,'_1)}}\,T_2(\vec{q}\,'_{31}\vec{q}_{31}\sqrt{|P_2^2|})\times$$
$$\times\sqrt{\frac{\omega_1(\vec{q}_{31})}{\omega_1(\vec{q}_1)}}\,d\vec{q}_{23}\,\phi_d(\vec{q}_{23}), \quad (4)$$

where

$$P_2^2 = P_0^2 - 2P_0\left(m_N + \frac{(\vec{q}_{23}+1/2\,\vec{q}_1)^2}{2m_N}\right) + m_N^2 \equiv P_2^2(\vec{q}_{23},\vec{q}_1),$$

$$\vec{q}\,''_{23} = -\vec{q}_{23} - \frac{1}{2}(\vec{q}\,'_1 - \vec{q}_1),$$

$$\vec{q}_{31} = \frac{\omega_1(\vec{q}_1)}{m_N+\omega_1(\vec{q}_1)}\vec{q}_{23} - \vec{q}_1\left(1 - \frac{\omega_1(\vec{q}_1)}{2(m_N+\omega_1(\vec{q}_1))}\right) = \quad (5)$$
$$= \frac{\omega_1(\vec{q}_1)}{m_N+\omega_1(\vec{q}_1)}\vec{q}_{23} + \vec{q}^{\,\circ}_{31},$$
$$\vec{q}\,'_{31} = \frac{\omega_1(\vec{q}\,'_1)}{m_N+\omega_1(\vec{q}\,'_1)}\vec{q}_{23} - \vec{q}\,'_1 + \vec{q}_1\,\frac{\omega_1(\vec{q}\,'_1)}{2[m_N+\omega_1(\vec{q}\,'_1)]} =$$
$$= \frac{\omega_1(\vec{q}\,'_1)}{m_N+\omega_1(\vec{q}\,'_1)}\vec{q}_{23} + \vec{q}\,'^{\circ}_{31}.$$

If we neglect the dependence of the T_2-matrix on momentum $\vec{q}_{23}$ (the approximation of the factorization) and of the corresponding factors $\sqrt{\omega_1(\vec{q}\,'_{31})/\omega_1(\vec{q}\,'_1)}$, $\sqrt{\omega_1(\vec{q}_{31})/\omega_1(\vec{q}_1)}$ then we get

$$T_{01}^{(1)}(\vec{q}\,'_{23}\vec{q}\,'_1;\vec{q}\,'_1 P_0) \simeq$$
$$\simeq 2\sqrt{\frac{\omega_1(\vec{q}\,'^{\circ}_{31})}{\omega_1(\vec{q}\,'_1)}}\,T_2[\vec{q}\,'^{\circ}_{31},\vec{q}^{\,\circ}_{31},P_2(0,\vec{q}_1)]\times \quad (6)$$
$$\times\sqrt{\frac{\omega_1(\vec{q}^{\,\circ}_{31})}{\omega_1(\vec{q}_1)}}\int\Psi_{\vec{q}\,'_{23}}\left[-\vec{q}_{23} - \frac{1}{2}(\vec{q}\,'_1 - \vec{q}_1)\right]d\vec{q}_{23}\,\phi_d(\vec{q}_{23}).$$

After the partial expansion in the separable model of the pair interaction for the partial t-matrices we have[1] from (1)

$$T_{01}^{J\mathcal{J}}(q'_{23}q'_1\alpha'_1;q_1\bar{\alpha}_1;P_0)=g_{L'_1}^{S'_1J'_1\mathcal{J}'_1}(q'_{23})/\mathfrak{D}^{S'_1J'_1\mathcal{J}'_1}[\xi(P_1^2)]\times$$
$$\times T_{11}^{J\mathcal{J}}(q_1\bar{\alpha}'_1;q_1\bar{\alpha}_1;P_0)+\frac{1}{2}\sum_{\alpha_2}(-1)^{3/2+\mathcal{J}_2}\hat{\mathcal{J}}_1\hat{\mathcal{J}}_2\begin{Bmatrix}1/2 & 1/2 & \mathcal{J}_1\\ 1 & \mathcal{J} & \mathcal{J}_2\end{Bmatrix}\times \quad (7)$$
$$\times\sum_{\lambda_1\lambda_2}\sum_{\mathcal{L}}G_{12}^{J}(\alpha'_1\alpha_2;\lambda_1\lambda_2\mathcal{L})\int_0^\infty h_{02}^{\lambda_1\lambda_2\mathcal{L}}(q'_{23}q'_1;q_2P_0)\times$$
$$\times q_2^2dq_2/\mathfrak{D}^{L_2Y_2\mathcal{J}_2}[\xi(P_2^2)]\,T_{2+3,1}^{J\mathcal{J}}(q_2\beta_2;q_1\bar{\beta}_1;P_0),$$

where the term corresponding to the first term of the expression (1) is absent due to the energy conservation. The system of equations for the elastic collision matrix $T_{11}^{J\mathcal{J}}$ and auxiliary matrix $T_{2+3,1}^{J\mathcal{J}}$ is given in refs.[2,3]. Here J and $\mathcal{J}$ are total angular and isospin momenta of the system, α_1 and α_2 are other quantum numbers of the π, NN and πN, N system. In refs.[2,3] the functions $g_{L'_1}^{S'_1J'_1\mathcal{J}'_1}$, $\mathfrak{D}_1^{S'_1J'_1\mathcal{J}'_1}$ and $g_{L_2}^{J_2\mathcal{J}_2}$, $\mathfrak{D}_2^{L_2J_2\mathcal{J}_2}$, which determine the NN and πN collision matrices in the separable model, are given too. The function h_{02} is defined as follows.

$$h_{02}^{\lambda_1\lambda_2\mathcal{L}}(q'_{23}q'_1;q_2P_0)=q_1'^{\lambda_2}q_2^{L_1-\lambda_1}\int_{-1}^{1}P_{\mathcal{L}}(\theta)\,d\theta\times$$
$$\times\frac{\delta(q'_{23}-q_{23})}{q_{23}'^{L_1+2}q_{31}^{L_2}}\,g_{L_2}^{J_2\mathcal{J}_2}(q_{31}) \quad (8)$$
$$a_2(q_{31},q_2,P_0)[q'_1\phi_{23}(q'_1q_2\theta)]^{\lambda_1}[q_2\phi_{31}(q'_1q_2\theta)]^{L_2-\lambda_2}\times$$
$$\sqrt{\frac{\omega_1(q_{31})\omega_3(q_{31})\omega_2(q'_{23})\omega_3(q'_{23})}{\omega_1(q'_1)\omega_3(q_3)\omega_2(q_2)\omega_3(q_3)}}$$

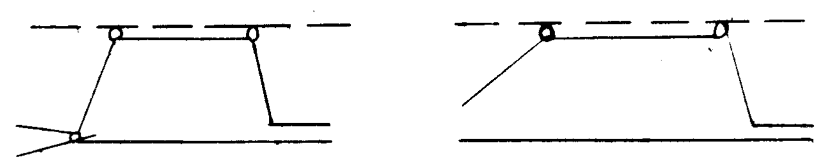
The expression of q_3, q_{23}, q_{31} versus of q_1, q_2, θ and the functions ϕ_{ij}, a_i and G_{12}^J are defined in our previous papers[1,2] in two cases:

1) when the relativistic limits are used for all three-particles and 2) when non-relativistic limit for nucleons is considered.

In the present paper the $\pi d\to\pi' NN$ processes are studied in the single πN-scattering approximation. It means that in the equations (8) and (3a,b) we have to put $U_{2+3,1}=U_{2+3,1}^{(1)}=2G_0^{-1}$ and $U_{11}=U_{11}^{(1)}=2T_2$. Such a kind of approximation turned out to be rather good for πd elastic scattering[1], namely, it gives the main contribution to the elastic collision matrix T_{11}. According to formula (3b) the desintegration matrix T_{01} can be obtained from the matrix T_{11} by replacing the deuteron wave function ϕ_d by wave function of two interacting nucleons in the final states. This allows us to hope that the single πN-scattering approximation will be rather good for the matrix T_{01} as well. By using this approximation in the separable (isobar) model for the pair interaction from equations (2) we have $T_{11}^{(1)}=2K_{12}\mathfrak{D}_2^{-1}K_{21}$ and $T_{2+3,1}^{(1)}=2K_{21}$[1]. As a result from (4) we get for the matrix

$$T_{01}^{(1)}=2K_{02}\mathfrak{D}_2^{-1}K_{21}+2g_1\mathfrak{D}_1^{-1}K_{12}\mathfrak{D}_2^{-1}K_{21}. \quad (9)$$

This expression is shown diagrammatically in Fig. A.



diag. 1 diag. 2

Fig. A

The first diagram describes the $\pi d\to\pi' NN$ processes in the single πN scattering approximation where the NN – final state interaction is neglected and the second one takes into account this interaction.

3. THE NUMERICAL CALCULATION PROCEDURE

In the calculations of the matrix T_{01} in the energy region studied only P_{33}-wave for πN-interactions was used, as to NN-interaction, we limited to the $^3S_1$ and $^1S_0$-waves. The total angular momentum was taken to be $J \leq 6$. As to the other quantum numbers of the π, NN and πN, N systems all the allowed values were included in the calculations.

The first term of (9) has no singularity due to the absence of the NN-final state interaction and the calculation reduces to integration of the two-dimension integral. This term was calculated with about 5% relative automatic accuracy.

The radial part of the second term of (6) including the final state NN interaction has the following form (for the sake of simplicity all quantum numbers are omitted)

$$T^{(1)}_{NN}(q'_{23}q'_1;q_1P_0)=\frac{g_{NN}(q'_{23})}{\mathcal{D}_{NN}[\xi(P_1^2)]}\int_0^\infty h_{12}(q'_1q_2P_0)\frac{q_2^2\,dq_2}{\mathcal{D}_{\pi N}[\xi(P_2^2)]}h_{21}(q_2q_1P_0), \tag{10}$$

where

$$h_{12}(q'_1q_2P_0)=h_{21}(q_2q'_1P_0)=\int_{-1}^{1}\frac{\mathcal{H}_{12}(q'_1q_2\theta,P_0)\,d\theta}{P_0+i0-e(q'^2_1,q_2^2,q'_1q_2\theta)}$$

$$e(q'^2_1,q_2,2q'_1q_2\theta)=\begin{cases}\omega_1(q'_1)+\omega_2(q_2)+\omega_3(q_3) & \text{the relativistic case}\\[4pt] 2m_N+m_\pi+\dfrac{q'^2_1}{2\eta_1}+\dfrac{q_2^2}{2\eta_2}+\dfrac{2q'_1q_2\theta}{2\eta_3} & \text{the non-relativistic case}\end{cases}$$

$q_3^2=q'^2_1+q_2^2+2q'_1q_2\theta$ the expression of the regular function $\mathcal{H}_{12}$ is given in ref. /1,2/.

The function $h_{12}(q'_1q_2\theta)$ in the integral (10) has logarithmic singularity (the well familiar singularity for Faddeev type equation) related to the fact that q'_1 varies in the range $0 \leq q'_1 < q_1$, where q_1 and q'_1

are pion momenta in the initial and final states respectively. For the numerical calculations the standard contour rotation method /4/ was used with deformation angle $\Phi=\frac{1}{2}\Phi_{max}$ (see, e.g., ref. /5,6/). It turned out that the results of the present calculations are more sensitive to the deformation angle Φ than for elastic πd scattering /6/. That is why for that reason we have handled the logarithmic singularity by using a new procedure described below. The expression (10) can be rewritten as

$$T^{(1)}_{NN}(q'_{23}q'_1;q_1P_0)=\frac{g_{NN}(q'_{23})}{\mathcal{D}_{NN}[\xi(P_1^2)]}\int_{-1}^{1}d\theta\int_0^\infty q_2^2\,dq_2\frac{F(q_2\theta;q'_1q_1;P_0)}{P_0+i0-e(q'^2_1,q_2^2,2q'_1q_2\theta)} \tag{11}$$

where

$$F(q_2\theta;q'_1q_1;P_0)\equiv F(q_2\theta)=\mathcal{H}_{12}(q'_1q_2\theta,P_0)\,\frac{h_{21}(q_2;q_1;P_0)}{\mathcal{D}_{\pi N}[\xi(P_2^2)]}.$$

Let us instead of the variables q_2 and $\theta=\cos\Theta$ take new variables x and y defined by $x=q_2\theta$ and $y=q_2\sqrt{1-\theta^2}$. Then we have

$$T^{(1)}_{NN}(q'_{23}q'_1;q_1P_0)=\frac{g_{NN}(q'_{23})}{\mathcal{D}_{NN}[\xi(P_1^2)]}\int_{-\infty}^{\infty}dx\{P\int_0^\infty\frac{y\,dy\,F(\sqrt{x^2+y^2},\frac{x}{\sqrt{x^2+y^2}})}{P_0-e(q'^2_1,x^2+y^2,2q'_1x)}$$

$$-i\pi\int_0^\infty y\,dy\,F(\sqrt{x^2+y^2},\frac{x}{\sqrt{x^2+y^2}})\,\delta[P_0-e(q'^2_1,x^2+y^2,2q'_1x)]. \tag{12}$$

In the first term of (12) the propagator $\frac{1}{P_0-e}$ resulting in the logarithmic singularity, can be rewritten in the form

$$\frac{1}{P_0-e(q'^2_1,x^2+y^2,2q'_1x)}=\begin{cases}\dfrac{2\eta_2(x,y)}{y_0^2(x)-y^2} & \text{the relativistic case}\\[4pt] \dfrac{2\eta_2}{y_0^2(x)-y^2} & \text{the non-relativistic case}\end{cases} \tag{13}$$

$$\eta_2(x,y)=\frac{[E-\omega_1(q'_1)-\omega_2(x^2+y^2)+\omega_3(q_3)]\{[E-\omega_1(q'_1)+\omega_2(x^2+y^2)]-\omega_3^2(q_3)}{8[E-\omega_1(q'_1)]^2}$$

where

$$y_0^2(x)=\begin{cases}\dfrac{\{[E-\omega_1(q_1')]^2-q_1'^2-2q_1'x\}^2}{4[E-\omega_1(q_1')]^2}-\omega_2^2(x) & \text{the relativistic case}\\[2ex] 2\eta_2[E-\dfrac{q_1'^2}{2\eta_1}-\dfrac{x^2}{2\eta_2}-\dfrac{2q_1'x}{2\eta_3}] & \text{the non-relativistic case.}\end{cases} \tag{14}$$

The first term of (12) after using of (13) can be regularized in the standard way

$$P\int_0^\infty y\,dy\,\frac{F(\sqrt{x^2+y^2},\,x/\sqrt{x^2+y^2})}{y_0^2(x)-y^2}= \int_0^\infty dy\,\frac{yF(\sqrt{x^2+y^2},\frac{x}{\sqrt{x^2+y^2}})-y_0F(\sqrt{x^2+y_0^2},\frac{x}{\sqrt{x^2+y_0^2}})}{y_0^2(x)-y^2}. \tag{15}$$

The advantage of the above described regularization procedure against the standard contour rotation method is that it does not include any additional parameter like the deformation angle. In addition now functions $\mathcal{H}_{12}$ and $\mathcal{H}_{21}$ are real. At the same time a new regularization procedure has a shortcoming: the function $f(q_2)=\mathfrak{D}_2^{-1}(q_2)\mathcal{H}_{21}(q_2,q_1P)$ now depends on two variables (x,y) instead of one q_2. Note that the numerical calculations can be made to be faster if one at the beginning calculates the function $f(q_2)$ in some main points q_2 and then uses an interpolation procedure in formulas (13-15). In our calculations we have taken 20-43 main points of interpolation and have used Lagrange interpolation polynomials of second and third order and splines of third order. It turned out that the numerical calculation results depend neither on the number of the main points nor on the interpolation procedure. All calculations were performed at the CDC-6500 and BESM-6 computers of JINR (Dubna).

The above described regularization procedure of the logarithmic singularity could be used for the numerical solution of equation (12) as well. But in this case it is more effective to use the interaction method [7].

4. RESULTS AND DISCUSSIONS

In this section we show results of the numerical calculations of the integral and differential cross sections of πd-scattering with the deuteron break-up and charge exchange reaction in the (3.3) resonance region we have got in the single πN-scattering approximation. All calculations were performed for the case when the pion relativistic kinematics is completely taken into account ("FRPK" [1]) and nucleons are considered in the non-relativistic limit. For the πN-scattering matrix the expression given in ref. [5] was used. Results of the calculations, obtained by the standard contour rotation method [4] are shown in figs. 1-6. Note that all results discussed below except those in fig. 5 are obtained by using the NN potential determined in ref. [8].

In fig. 1 the cross section of the deuteron desintegration and charge exchange reaction are shown in comparison with the total πd scattering cross section and the integral elastic scattering cross section obtained in our previous paper [1] in the single scattering approximation. As one can see, the difference between the total πd scattering cross section and the sum of the elastic cross section and the deuteron break-up and charge exchange reaction cross sections is sizable, namely at $T_\pi^{CM}=160$ MeV it amounts about 65 mb - 30% of the total cross section. The cause for this difference could be the number of approximation used in our calculations: neglect the multiple πN-scattering, neglect all but S-waves in the NN-interactions, the P_{33}-wave approximation in the πN-interaction and neglect the influence of the genuine pion absorption channel on the other channel. Note that pion absorption cross section by deuteron itself is relatively small [9] and of the same order as charge exchange reaction cross section. In addition this difference is connected with the separable approximation of pair interaction particularly of NN interaction used in the πd scattering study. This model has some physical foundations only near the resonance or bound state.

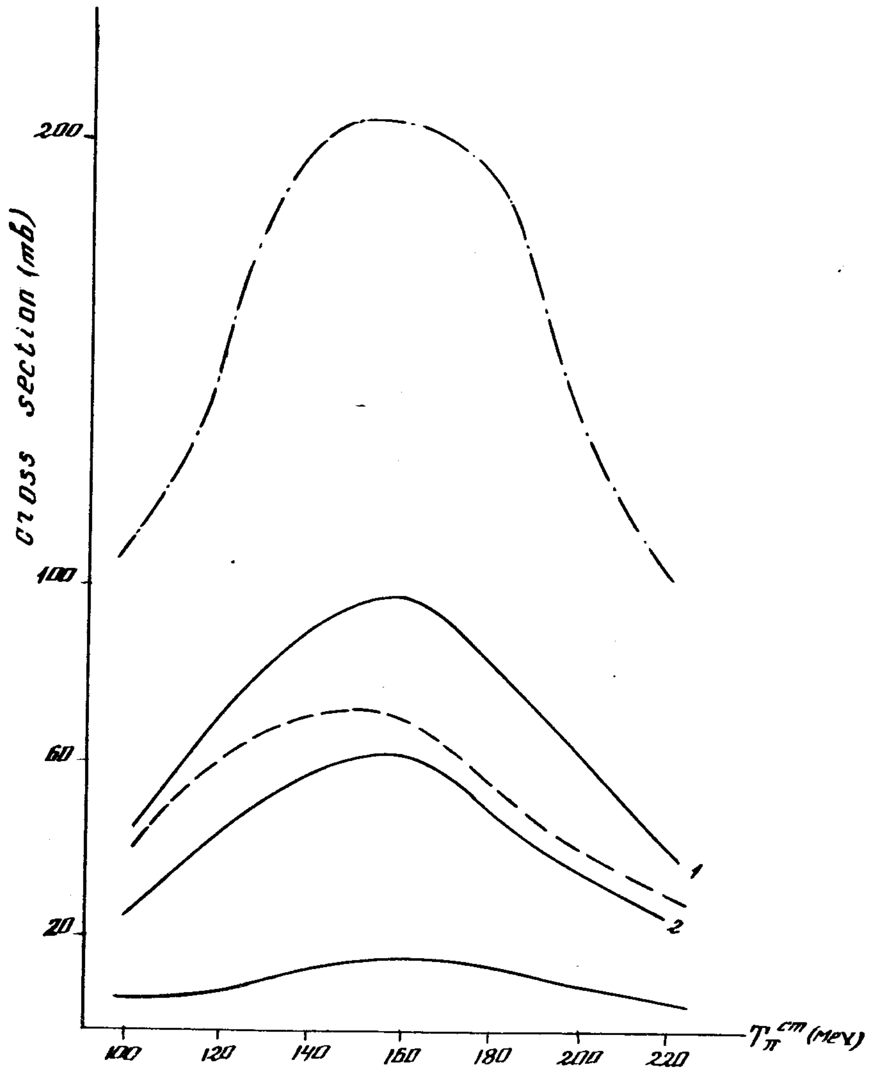


Fig. 1. The πd scattering cross section: - · - · - total cross section and - - - - - - elastic integral cross section taken from ref.[1]. Curves 1 and 2 - deuteron break-up reactions. Curves 1 - final state NN interaction neglected, curves 2 - with NN interaction. Solid curve - charge-exchange reaction.

The comparison of the solid curves 1 and 2 in fig. 1 demonstrates the importance of the final state NN -interaction which reduces the deuteron desintegration cross section. Note that the term (6) which stands for the final state NN -interaction does not contribute to the charge exchange cross section due to selection rules. The differential cross section for deuteron break-up shown in fig. 2 demonstrates the importance for diagram 2 in fig. A to be taken into account. The relative value of this effect depends essentially on the pion scattering angle (in particular, it is small at backward angles). If we compare the elastic scattering differential cross section calculated in the single πN-scattering approximation and shown in the same fig. 2 with the deuteron desintegration differential cross section we can see that at small angles the deuteron break-up cross section is rather smaller than the elastic cross section due to the NN final state interaction. As for the backward angle the situation is opposite and it does not depend on the NN final state interaction in the $\pi d \to \pi$ NN channel. The $\pi d \to \pi'$NN processes are characterized not only by the differential and integral cross sections but by the scattered pion momentum distribution (or by the relative momentum distribution of nucleons in the final states) with the fixed incident pion energy. These distributions calculated by us are shown in figs. 3 and 4. We see that the pion momentum distribution is concentrated in the narrow range around the allowed maximum value of the scattering pion momentum, and the NN final state interaction makes the peak more sharp. The increase in the incident pion energy leads to the same effect.

Keeping in mind the sensibility of the different characteristics of the $\pi d \to \pi'$NN processes to the final state interaction effect, it seems interesting to clear up the dependence of this effect on the choice of the NN -interaction potential. We have used: the Lamanuche type potential [8] and the unitary pole approximation to the Rend potential [10], which

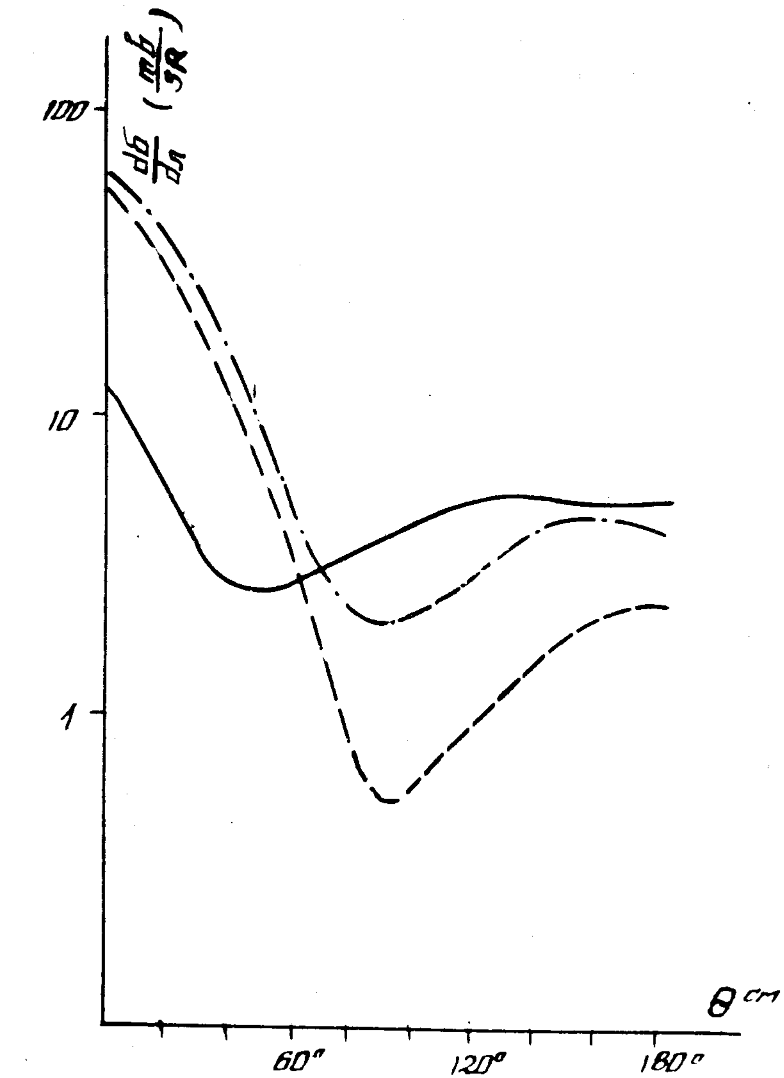


Fig. 2. The πd scattering differential cross sections at T_{π}^{CM} = 160 MeV: - - - elastic scattering cross section taken from ref. /1/. ——— deuteron break-up reaction with the final state interaction, —·—·— without NN interaction.

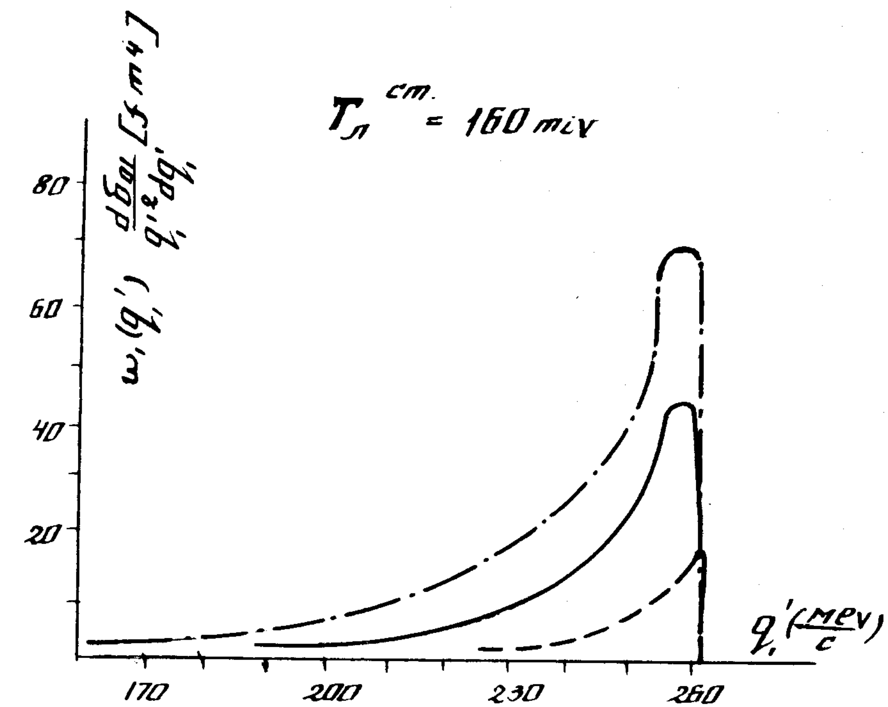


Fig. 3. The scattered pion momentum distribution: ——— deuteron break-up with the final state NN interaction, -·-·- without NN interaction, - - - charge-exchange reaction.

describes NN -scattering phase shifts up to 200 MeV, and the energy-dependence potential /11/ fitted to NN -scattering phase shifts up to 400 MeV. The comparison of curves in the fig. 5, where the energy dependence of deuteron break-up cross section for the different NN-potential is shown, demonstrates cross sections NN potential dependence, which is

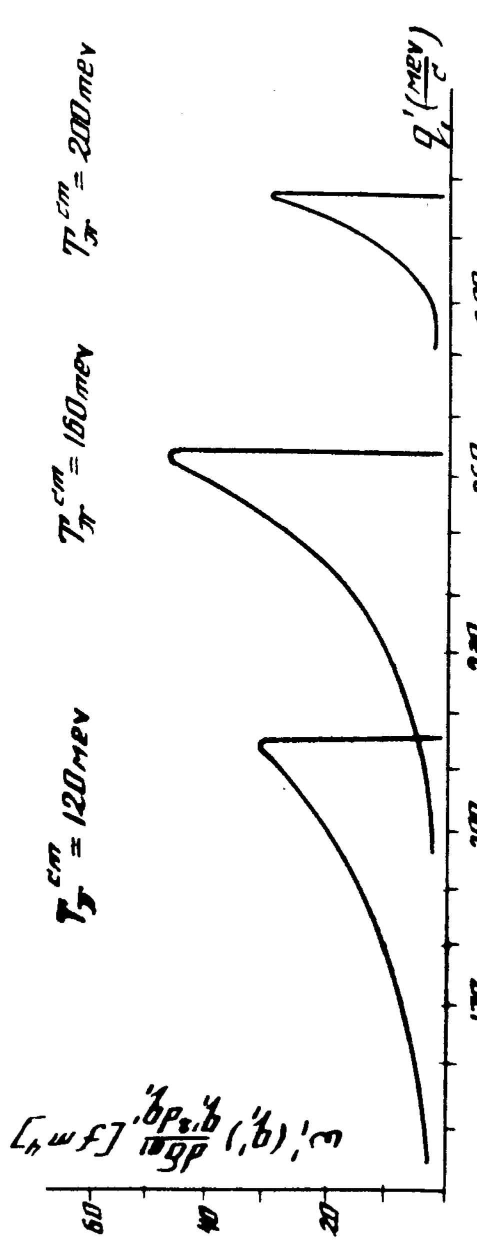


Fig. 4. The scattered pion momentum distribution for the deuteron break-up reaction at different energies.

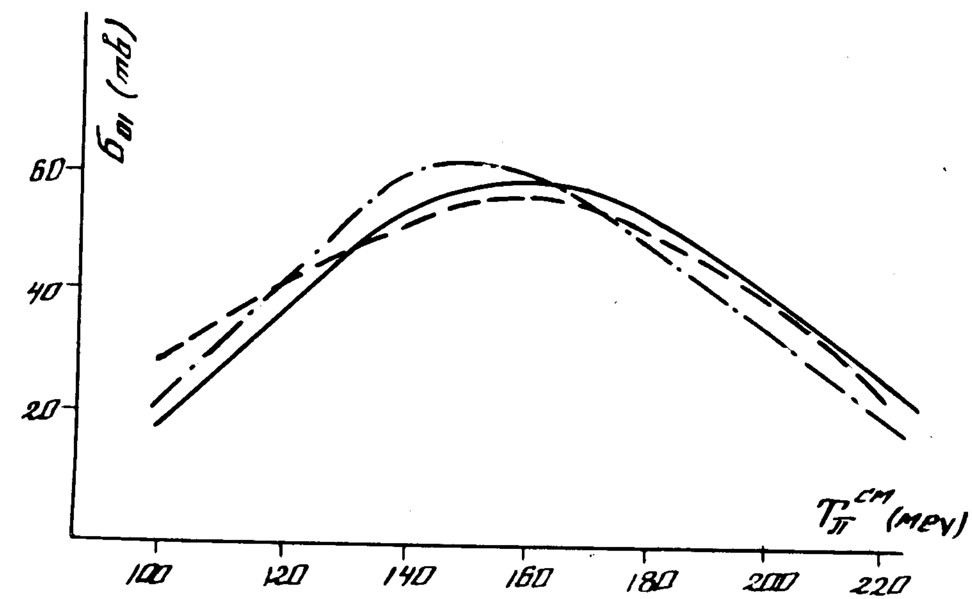


Fig. 5. The integral cross sections of deuteron break-up reaction with the NN final state interaction for different NN potential: ——— /8/ , -·- /11/ and - - - /10/.

more apparent than in the πd elastic scattering case. But at the same time it isn't enough to make the choice between different NN potentials. Likely, this is connected with the fact that the different potentials used in our calculations have the same form and differ from each other only by parametrization. The importance of the NN final state interaction effect in the deuteron break-up reaction is seen from the results of ref./12/ obtained under the following assumptions: 1) neglect of the Fermi motion, i.e., the use of the transition matrix (6), 2) the asymptotic expression for the wave function $\Psi^{(-)}_{\vec{q}'_{23}}$ is used, the parameters of which were determined in the scattering length approximation by orthogonalizing this function with the deuteron wave function, 3) the pion relativistic kinematics and partial wave structure of the three-body amplitude are treated approximately. In addition only one characteristic of the $\pi d \to \pi NN$ reactions, the differential cross section, has been calculated.

The behaviour of the scattered pion angular distribution in the deuteron break-up reactions at small angles is very important for clarifying the role of NN - final state interaction. Indeed, when the Fermi motion is neglected, taking into account the NN -final state interaction reduces considerably the small-angles cross section due to the orthogonality of the wave function in the initial and final states of NN system, as we can see from formula (6). But if we take into account the Fermi motion, as it is done in the present study, then the cross section at small angles turned out to be rather large. Therefore the knowledge of the experimental differential cross section for deuteron break-up reaction at small angles, allows us to check the validity of the approximation of the factorization (6).

At present there exist some experimental data on the angular distribution of the scattered pions in the deuteron desintegration and charge-exchange reactions[13]. In fig. 6 the results of our calculations are compared with the experimental data at T^L_π = =182 MeV. The theoretical curves give only a qualitative description of the experimental angular distribution, namely, for the break-up we have got deep minima and for charge exchange reaction two maxima, but their locations are shifted against the experimental one. Such a difference between theory and experiment is probably caused by the approximations mentioned above where the results for integral cross sections were discussed. It is clear that the differential cross sections are more sensitive to these approximation than the integral cross sections.

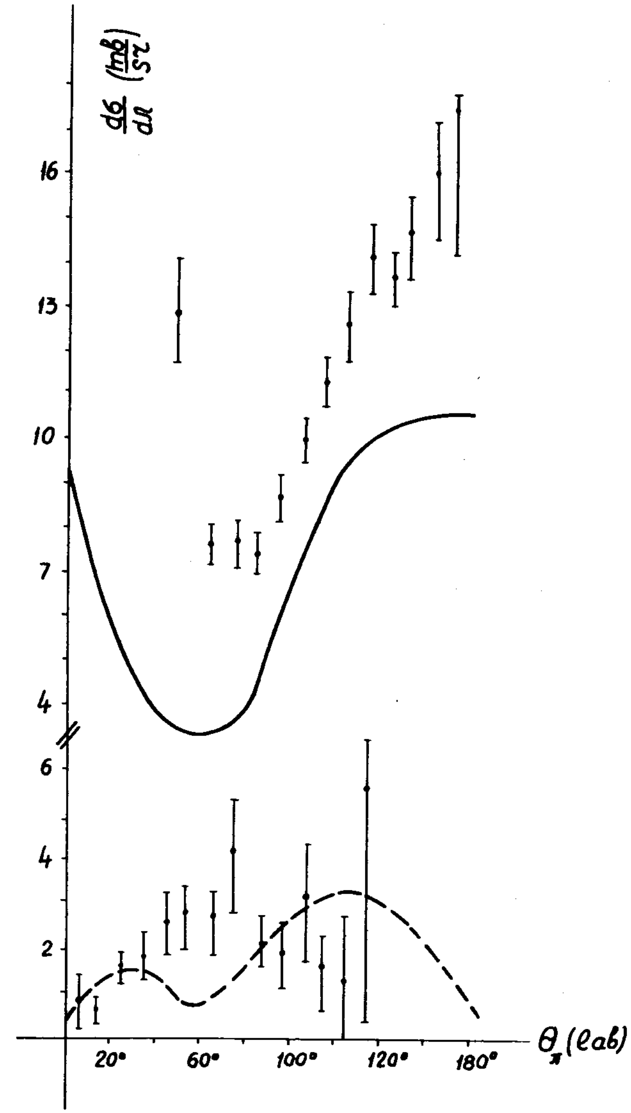


Fig. 6. The comparison of the calculation results with experimental data at T^{CM}_π = 160 MeV: —— deuteron break-up reaction, - - - charge-exchange reaction.

Fig. 7. The energy dependence of integral cross section of deuteron-break-up reaction calculated by using different regularization procedures: ——— contour integration method, - - - new procedure suggested in the present paper.

As was mentioned the numerical results discussed above depend on the calculation method, namely, on the contour deformation angle Φ. For the illustration of the dependence of results on the integration procedure, in fig. 7 there are shown the integral cross sections for the deuteron break-up reaction calculated by the contour rotation method and by the new procedure described above. As one can see, there is some regular shift in the cross section value but the general feature is unchanged. Therefore all our conclusions about the reactions studied remain valid.

The general conclusion we come to is as follows: Further investigations of πd scattering in (3.3) resonance region are necessary to establish the reason of the discrepancy between theory and experiment for the differential cross sections of the deuteron break-up and charge-exchange reactions. Moreover, the same imput gives better results for the elastic πd scattering. The further study is necessary too for better understanding of the pion deuteron interaction dynamics.

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