To the nature of intermediate- and short-range nucleon-nucleon interaction

Vladimir I. Kukulin, I. T. Obukhovsky, V. N. Pomerantsev

Institute of Nuclear Physics, Moscow State University, 119899 Moscow, Russia

Abstract

Instead of the Yukawa mechanism for intermediate- and short-range interaction some new approach based on formation of the symmetric six-quark bag in the state $|(0s)^6[\bar{6}]_X, L = 0\rangle$ dressed due to strong coupling to $\pi$, $\sigma$ and $\rho$ fields are suggested. This new mechanism offers both a strong intermediate-range attraction which replaces the effective $\sigma$-exchange (or excitation of two isobars in the intermediate state) in traditional force models and also short-range repulsion. Simple illustrative model is developed which demonstrates clearly how well the suggested new mechanism can reproduce $NN$ data.

It was found in recent years that the traditional models for $NN$ forces, based on the Yukawa concept of one- or two-meson exchanges between free nucleons [1] even at the quark level lead to very numerous disagreements with newest precise experimental data for few-nucleon observables (especially for spin-polarized particles) [2–4]. There are also numerous inner inconsistencies and disagreements between the traditional $NN$ force models and predictions of fundamental theories for meson-baryon interaction [5] (e.g. for meson-nucleon form factors). All these disagreements stimulate strongly the new attempts to develop alternative force models based either on chiral perturbation theory or a new quark-meson models. Our recent studies in the field [2,4–6] have led us to a principally new mechanism for intermediate- and short-range $NN$ forces. This mechanism can also shed some light to the puzzles in baryon spectroscopy (e.g. normal ordering in $\Lambda$-sector and inverse ordering in nucleon sector for excited negative and positive parity states). The
new model is based on the important observation [6,7] that two possible six-quark space symmetries in even \( NN \) partial waves, viz. \(|s^{66}_L = 0\rangle\) and \(|s^4p^2_4^2 L = 0, 2\rangle\) which are allowed for \( NN \) system in \( s\)- and \( d\)-partial waves corresponds to the states of different nature. The former states have almost the same projections into various baryon-baryon (i.e. \( NN, \Delta\Delta, CC \)) channels and thus correspond to bag-like intermediate states while the coherent superposition of the states of second type are projected mainly into \( NN \) channel with a large weight and thus can be presented as clusterised \( NN \) states with nodal \( NN \) relative motion wave functions [6,7] which are similar to those derived from our previous Moscow potential model [7].

In the present work we develop this picture much further on the quark-meson microscopic basis and derive the microscopic \( NN \) transition amplitudes through six-quark +2\( \pi \) intermediate states in \( s\)-channel (see Fig. 1). The transition is accompanied by a virtual emission and subsequent absorption of two tightly correlated pions by diquark pairs or, alternatively, by two 1\( p \)-shell quarks when they jump from 1\( p \)- to the 0\( s \)-shell orbit or vice versa. These two pions can form both the scalar \( \sigma \) and vector \( \rho \) mesons which surround the symmetric six-quark bag. Thus we adopt the \( s\)-channel quark-meson intermediate states as shown in Fig.1, the transition amplitude being determined by \( s\)-channel singularities in sharp contrast to the Yukawa mechanism driven by \( t\)-channel meson exchange. This \( s\)-channel mechanism, being combined with an additional orthogonality requirement [4] (see below), can describe both the short-range repulsion and the medium range attraction and can replace the \( t\)-channel exchange by \( \sigma \)- and \( \omega \)-mesons in the conventional Yukawa-type picture of the \( NN \) force[1].

\[1\] Surely together with this specific six-quark mechanism we should take into consideration also the traditional Yukawa mechanism for \( \pi \)-, 2\( \pi \)- and \( \rho \)- (but not \( \sigma \)-) meson exchanges between isolated nucleons. However these meson-exchange contributions are essential only at the separations beyond the intermediate six-quark bag (\( > 1 \text{ fm} \)) or in high partial waves (\( L > 3 \)). In the lowest partial waves, the intermediate dressed six-quark bag gives a dominating contribution for the total \( NN \) interaction.
In multiquark systems or in high density nuclear matter some phase transition may happen when the quark density or the temperature of the system is increased [8]. This phase transition leads to a partial restoration of the broken chiral symmetry and thus to the reduction of the $\sigma$-meson and constituent-quark masses [8]. The significant reduction of $\rho$-meson mass in the nuclear matter has been predicted also by the so called Brown-Rho scaling. The most probable consequence of the restoration should be strengthening of the sigma-meson field in the $NN$ overlap region. This could be modeled by "dressing" of the most compact six-quark configurations $|s^6[6]_X L = 0\rangle$ and $|s^5p[51]_X L = 1\rangle$ inside the $NN$ overlap region with an effective sigma-meson field. The "$\sigma$" or a similar "scalar-isoscalar meson" is assumed to exist only in a high density environment and not in the vacuum, contrary to the $\pi$ and $\rho$ mesons [9]. Thus the scalar- and vector-meson clouds will stabilize the multi-quark bag due to a partial chiral symmetry restoration effect in the dense multi-quark system and thus enhance all the contributions of such a type. The picture of $NN$ interaction emerged from the model can be referred to as the "dressed" 6q bag (DB) model (see Fig. 1).

Starting from this quark-hadron picture we assume that the total wave function of the system $\Psi_{\text{total}}^L$ at short $NN$ distances (in lower partial waves $L=0, 1$) consists of two parts with different nature: the "proper $NN$ component", the quark-cluster part of which, $\Psi_{NN}^L(6q)$, is dominated by the excited six-quark configurations $s^4p^2$ at $L=0$ (or the $s^3p^3$ at $L=1$), and the "proper dressed-bag component", the quark part of which, $\Psi_{DB}^L(6q)$, is dominated by the compact configurations $s^6$ (or the $s^5p$ at $L=1$) with a maximal overlap of all six quarks. The bag-like configurations $s^6$ and $s^5p$ which are dressed by an enhanced $\sigma$ field, viz. $\Psi_{DB}^L = |6q + \sigma(\pi\pi)\rangle$ plays the same role in the hadronic sector of our model as the $\Delta\Delta + \pi\pi$ intermediate state in the standard (hadron) models of the $NN$ interaction [1]. However, the dressed bag component $|6q + \sigma(\pi\pi)\rangle$ has a much more extended physical content than the $\Delta\Delta + \pi\pi$ intermediate state in the traditional $NN$-models as: (i) the six-quark part of the DB implies a coherent sum over all the possible baryon-baryon pairs in the cluster decomposition $3q + 3q$ [11]; (ii) the $\sigma$-meson (or $\pi + \pi$) part of the DB is probably enhanced due to the (partial) chiral symmetry restoration which implies the
\(\sigma\)-meson and constituent quark masses to be noticeably reduced [8].

Thus we can treat the DB states as a new component in the Fock space or a new (closed at \(E < E_0 \sim 600\) MeV) channel in the coupled channel approach to the \(NN\) scattering and write the total \(NN\) wave function in the form

\[
\Psi_{\text{total}}^L = \begin{pmatrix} \Psi_{NN}^L(6q) \\ \Psi_{DB}^L(6q + \sigma) \end{pmatrix}, \quad \Psi_{DB}^L(6q + \sigma) = \Psi_0^L(6q) \otimes \sigma(\pi\pi),
\]

(1)

where the "proper" \(NN\) wave function \(\Psi_{NN}^L(6q)\) is orthogonal to the six-quark part of the DB component \(\Psi_0^L(6q)\) [7], i.e. \(\langle \Psi_{NN}^L(6q) | \Psi_0^L(6q) \rangle = 0\), at \(L=0,1\).

The transition amplitude from the initial \(s^4p^2(L = 0, 2)\) (or \(s^3p^3\) at \(L = 1, 3\)) six-quark configurations (the coherent superposition of those corresponds to the proper \(NN\) channel) to the intermediate ones \(s^6(L = 0) + (\pi\pi)\) (or \(s^5p + (\pi\pi)\) at \(L = 1\)) is accompanied with an emission of the S-wave correlated \(\pi + \pi\) pair, the both pions being created in the \(s\)-wave due to conservation of parity and angular momentum.

The intermediate six-quark configuration \(s^5p[51]_X\) (denoted by vertical dashed lines in the Fig. 1) have fixed quantum numbers which are determined by the initial \((NN)\) and intermediate ("dressed" bag \(6q + \sigma\)) states. The second (after the first pion emission) state in the channel \(ST = 01, J^P = 0^+\) has quantum numbers of the so-called \(d'\)-dibaryon \(d' = |(0s)^5(1p)[51]_X L=1, [321]_{CS}(ST = 10)J^P = 0^-\) (see, e.g. [11]). In the channel \(ST = 10, J^P = 1^+\) the transition goes via another intermediate state \(d'' = |(0s)^5(1p)[51]_X L=1[2^21^2]_{CS}(ST = 01)J^P = 1^-\), which is a partner of the \(d'\) by \(S \leftrightarrow T\) interchanged. Both intermediate configurations \(d'\) and \(d''\) cannot decay into the two-nucleon channel as their quantum numbers do not satisfy the Pauli exclusion principle for two nucleons [11].

The transition amplitude is calculated here in the framework of the well known quark-pair-creation model (QPCM) [12] (see also [11]) and the transition operator for the emis-

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\(^2\) The "compact" configurations \(s^6\) and \(s^5p\) are usually included in the resonating-group-method (RGM) calculations for the \(NN\) system but without the strong \(\sigma\) and \(\rho\)-meson fields they play quite a passive role providing only "dying out" of the \(NN\) wave function at short range as a result of the strong \(NN\) repulsion in these quark states [10].
sion of the pion $\pi^\lambda$ ($\lambda = 0, \pm$) by a single (e.g., the j-th) quark in a six-quark system $H^{(j)}_\lambda(k_j)$ is taken in the form proposed earlier \textsuperscript{11}. The $\pi + \pi \to \sigma$ transition amplitude is determined \textsuperscript{13} to be proportional to the overlap of the two-pion and the $\sigma$-meson wave functions: $\langle \pi(k)\pi(k')|H_{\pi\pi}\sigma \rangle = g_{\pi\pi\sigma}F_{\pi\pi\sigma}((k - k')^2)$, $F(k^2) = \exp(-\frac{1}{2}k^2b_\pi^2)$. In the limit of a point-like pion the operator $H^{(6)}_\lambda$ goes to the standard pseudo-vector (PV) quark-pion coupling. Thus the phenomenological coupling constant of the QPCM is normalized to the standard PV $\pi qq$ coupling constant $f_{\pi qq} = \frac{3}{5}f_{\pi NN}$.

The amplitude $NN^{L=0.2}(s^4p^2) \to d'(d'') + \pi \to 6q(s^6) + \sigma$ can be expressed through a matrix element of a transition operator $\Omega_{NN \to d_0 + \sigma}^L(6) = \int d^3r \Psi_{NN}^L(E;r) \Omega_{NN \to d_0 + \sigma}^L(E;r;k)$, where $\Psi_{NN}^L(E;r)$ is the proper $NN$ wave function in the sense of Eq. (1), $E = 2m_N + p_N^2/m_N$ and the plane-wave approximation is used for the intermediate DB state $d_0 + \sigma$. The operator $\Omega_{NN \to d_0 + \sigma}$ incorporates the contribution of the six-quark state (in the left hand part of the graph of FIG. 1) projected onto two-nucleon clusters of the initial state and can be written as an integral of the elementary six-quark transition amplitude over both inner coordinates of quark clusters (viz. N(123), N(456), $\pi$ and $\sigma$) and the pion momenta $k_5$ and $k_6$:

$$\Omega_{NN \to d_0 + \sigma}^L(E;r;k) = 15 \int d^3k_5 \int d^3k_6 \delta(k_5 + k_6 - k) \times \sum_\lambda \frac{(-1)^{1-\lambda}}{3} \frac{\sqrt{10} \langle N(6)H_{\pi\pi}\sigma(k_6)d' (d'')|d''(d')|H_{\pi\pi\sigma}(k_5)\rangle \langle \sigma|d_0 \rangle g_{\pi\pi\sigma}F_{\pi\pi\sigma}((k_5 - k_6)^2)}{\left[ m_{d'} + \frac{k_5^2}{m_{d'}} + \omega_\pi(k_6) - E \right] \left[ m_{d_0} + \frac{k_5^2}{m_{d_0}} + \omega_\pi(k_5) + \omega_\pi(k_6) - E \right]}$$

The numerical factor 15 in front of the integral counts the number of $qq$ pairs in the six-quark system.

All the matrix elements of interest are calculated using the f.p.c. technique \textsuperscript{6,14} and are reduced to a product of the vertex constant $v_{f\pi AB}$ (in the QPCM $v = -i(f_{\pi qq}/m_\pi)((2\pi)^32\omega_\pi)^{-1/2}$), form factor $F_{\pi AB}(k_i)$ and a kinematical factor $\omega_\pi(k_i)/m_\pi b$ \textsuperscript{11}:

$$\langle d^L_f|H_{\lambda}^{(6)}(k_6)|d' \rangle = v \frac{\omega_\pi(k_6)}{m_\pi b} \int d_{f'f}F_{\pi AB}(k_6^2) \sum_{d'd'} \Sigma_{d'}d' \ T_{-\lambda}^{d'd'}$$

(and a similar expression for $\langle d'|H_{\lambda}^{(5)}(k_5)|d_0 \rangle$). In Eq. (3) the $\Sigma_{d'd'}$ and $T_{-\lambda}^{d'd'}$ are transition operators in the space of total spin and isospin of the six-quark states $d_f$ and $d'$. The
transition form factors \( F^L \) depend on the angular momentum \( L=0(2) \) of the initial state:

\[
F^L_{\pi d_d}(k^2_0) = (1 + a_L \frac{5k^2_0b^2_N}{24}) \exp(-5k^2_0b^2_N/24), \quad F^L_{\pi d_d}(k^2_0) = \exp(-5k^2_0b^2_N/24),
\]

with \( a_L=0 = \frac{1}{3} \) and \( a_L=2 = -\frac{2}{3} \). As a result one gets quite a simple expression for the transition operator \( \Phi \) in the case of \( S \) and \( D \) partial waves in the initial \( NN \) channel:

\[
\Omega^L_{NN \rightarrow d_0 + \sigma}(E; \mathbf{r}, \mathbf{k}) = g_L e^{-5k^2_0b^2_N/48} D^L(E, k) \varphi_{2L}(\mathbf{r}), \quad L = 0, 2,
\]

where \( \varphi_{2L}(\mathbf{r}) \) is the h.o. wavefunction and the value \( g_L \) means an effective strength constant of the transition \( N + N \rightarrow d_0 + \sigma \) from initial (cluster-like) \( NN \) state to the intermediate "dressed" bag configuration, which takes the form:

\[
g_L = \frac{f^2_{\pi q} g_{\pi \sigma}}{m^2_\pi m^2_{d_0} b_N^2} C_L, \quad \text{with} \quad C_L = 15 f^4_{\pi d_0} \sum_f J^L_{\pi d_0} \Gamma^L_{d_0} U^L_{NN} = \frac{1}{144} \times \begin{cases} -\frac{617}{200\sqrt{5}}, & L = 0 \\ \frac{11}{8!}, & L = 2 \end{cases}.
\]

The factor in \( \Gamma^L_{d_0} \) in Eq. (5) is a coordinate part of the f.p.c. of the translationally-invariant shell model (TISM), while the \( U^L_{NN} \) is the respective CST part of it \( \Phi \). The function \( D^L(E, k) \) in Eq. (4) corresponds to the loop integration in Eq. (2). Thus the calculation of the multi-loop diagram in Fig. 1 results in a separable amplitude of the \( NN \) interaction with left- and right-hand-side vertices being expressed in the form (4) while the loop integral over the intermediate \( |s^0 + \sigma \rangle \) state is expressed through the function (a generalized propagator of the dressed bag):

\[
G^L_{LL'}(E) = \int \frac{k^2 dk \exp \left(-\frac{5k^2 b^2_N}{24}\right) D^L(E, k) D^L(E, k)}{E - \mathcal{E}(k)}, \quad \mathcal{E}(k) = m_\sigma + m_{d_0} + \frac{k^2}{2m_{d_0}},
\]

where the \( m_{d_0} = m_\sigma m_{d_0}/(m_\sigma + m_{d_0}) \) is the reduced mass in the DB state. In accordance with this, the contribution of the mechanism of Fig. 1 to the \( NN \) interaction in the \( S \) and \( D \) partial waves can be expressed through the matrix element:

\[
A^{UL}_{NN \rightarrow d_0 + \sigma \rightarrow NN} = \int d^3r' d^3r \Psi^L_{NN}(E; \mathbf{r}) V^{UL}_{E}(\mathbf{r}', \mathbf{r}) \Psi^L_{NN}(E; \mathbf{r}),
\]

where \( V^{UL}_{E}(\mathbf{r}', \mathbf{r}) \) is a separable potential matrix of the form

\[
V^{UL}_{E}(\mathbf{r}', \mathbf{r}) = \begin{pmatrix}
g_0^2 G_{00}(E) \phi_{2s}(\mathbf{r}') \phi_{2s}(\mathbf{r}) & g_0 g_2 G_{02}(E) \phi_{2s}(\mathbf{r}') \phi_{2d}(\mathbf{r}) \\
g_2 g_0 G_{20}(E) \phi_{2d}(\mathbf{r}') \phi_{2s}(\mathbf{r}) & g_2^2 G_{22}(E) \phi_{2d}(\mathbf{r}') \phi_{2d}(\mathbf{r})
\end{pmatrix}.
\]
The interaction operator (7) mixes $S$- and $D$-partial waves in the triplet $NN$ channel and thus it leads to a specific tensor mixing with the range $\sim 1 \text{ fm}$ (about that of the intermediate DB state). Thus the proposed new mechanism results in a specific matrix separable form of the $NN$ interaction with nodal (in $S$- in $P$-partial waves) form factors and a specific tensor mixing of new type [15].

In the case of (partial) restoration of the chiral symmetry inside the (compact) symmetric six-quark bag the effective $\sigma$-meson mass and width should be much lower than its values accepted for the conventional OBE models [1,2]. Then the position of the branch point $E_0 = m_{d_0} + m_\sigma$ of the function $G_{LL}(E)$ in Eq. (7) will shift to lower energies and the contribution of this (attractive) mechanism to the low-energy $NN$ interaction becomes more important. In other words, instead of the (artificial) increase of the cut-off parameters in the $\pi NN (\sigma NN, \rho NN, \ldots, etc.)$ form factors in traditional OBE models [1] we adopt the (natural) decrease of the denominator in Eq. (6). Furthermore the complicated energy dependence dictated by Eq. (6) may be well approximated by a pole term $\sim (E - \bar{E}_0)^{-1}$ with the effective pole position $\bar{E}_0$ either calculated or simply fitted to the $NN$ phase shifts.

To illustrate the proposed new mechanism we built a simple model which includes the main features of the suggested mechanism for $NN$-interaction [3]. The model includes only a few parameters for coupled partial waves and can fit the $NN$ phase shifts on the broad energy range $0 \div 600 \text{ MeV}$, or even until $1200 \text{ MeV}$, using a soft cut-off parameter $\Lambda_{\pi NN} \sim 0.6 \text{ GeV}$ (in sharp contrast to any OBE model) which is required by all microscopic models for meson-baryon coupling. The model interaction consists of three terms: $V_{NN} = V_{\text{orth}} + V_{NqN} + V_{\text{OPE}}$ with $V_{\text{orth}} = \lambda_0 |\varphi_0\rangle \langle \varphi_0|$, ($\lambda_0 \to \infty$), providing the condition of orthogonality between the proper $NN$ channel and the six-quark part of the intermediate bag in $S$- and $P$-waves. The one-pion-exchange potential $V_{\text{OPE}}$ is taken here with soft dipole cut-off, while the separable term $V_{NqN}$ for the single channel case takes the form:

$$V_{NqN} = \lambda_0 |\varphi_0\rangle \langle \varphi_0|.$$ 

This nodal character of the form factors makes it possible to explain within this mechanism the origin of the $NN$ repulsive core by the nodes in transition form factors.
\[ V_{NqN} = \frac{E_0^2}{(E - E_0)} \lambda |\varphi\rangle \langle \varphi|, \] and for coupled channels it is a \((2 \times 2)\)-matrix:

\[
V_{NqN} = \frac{E_0^2}{E - E_0} \begin{pmatrix}
\lambda_{11} |\varphi_1\rangle \langle \varphi_1| & \lambda_{12} |\varphi_1\rangle \langle \varphi_2| \\
\lambda_{21} |\varphi_2\rangle \langle \varphi_1| & \lambda_{22} |\varphi_2\rangle \langle \varphi_2| 
\end{pmatrix},
\] (8)

with \(\lambda_{12} = \lambda_{21}\). This form corresponds basically to the general separable potential derived in Eq.(7). For all form factors entering \(V_{NqN}\) we use the simple Gaussian form with one scale parameter \(r_0\): \(\varphi_i(r) = N_{i} L_{i}+1 \exp(-r^2/2r_0^2)\). In the calculations the averaged value of pion-nucleon coupling constant \(f_{\pi NN}^2/(4\pi) = 0.075\) and a soft cut-off parameter with values \(\Lambda_{\pi NN} = \Lambda_{\text{dip}} = 0.60 \div 0.73\) GeV have been used. The results of the fits of the model parameters \(\lambda_k\) (or \(\lambda_{jk}\)), \(r_0\) and \(E_0\) to the \(NN\) phase shift analysis data are displayed on Fig. 2. The parameter \(E_0\) corresponds to the sum of the six-quark bag energy and the effective \(\sigma\)-meson mass inside the six-quark bag. It is quite evident this simple model is able to describe the \(NN\) low partial waves up to \(E_{\text{lab}} = 600\) MeV very well. The respective phase shifts and the mixing parameter \(\varepsilon_1\) are compared in Fig. 2 with data of a recent phase shift analysis (SAID, solution SP99).

Moreover, it was very surprising to find out that such a simple model gives very good description for \(^1S_0\) phase shifts even up to \(E_{\text{lab}} = 1200\) MeV [9]. It is very instructive here to discuss the description of phase shifts in triplet coupled channels \(^3S_1 - ^3D_1\), and especially the behavior of the mixing parameter \(\varepsilon_1\) with increasing energy. Without the (quark-bag induced) non-diagonal mixing potential (i.e. at \(\lambda_{12} = 0\)) the behavior of \(\varepsilon_1\) is correct only at very low energies (see the dashed line on the lower right panel in Fig. 2). The increase of the cut-off parameter \(\Lambda_{\pi NN}\) up to values 0.8 GeV does not help to get a better agreement with the data, but on the contrary, destroys the good description at low energies (the dotted line in the panel for \(\varepsilon_1\) in Fig. 2). Introducing the quark-bag induced mixing (\(\lambda_{12} \neq 0\) in Eq.(8)), which we predict on the base of the suggested new mechanism, allows us to reproduce the behavior of \(\varepsilon_1\) (and \(^3S_1 - ^3D_1\) phase shifts as well) with a reasonable accuracy until the energy as high as \(E_{\text{lab}} \sim 600\) MeV, but for sufficiently small values of \(\Lambda_{\pi NN}\) only. The best fit result for the \(\varepsilon_1\) mixing parameter is

\[4\] The respective values of parameters can be found in [9].
shown on the lower right panel of Fig. 2 (by solid line) and is attained with the value of $\Lambda_{\pi NN} = 0.594$ GeV. In this case the condition $\lambda_{12}^2 = \lambda_{11} \lambda_{22}$ is satisfied with high accuracy. Just this condition follows from our assumption that the quark-bag induced $S - D$ mixing arises due to coupling of the $NN$ channel with $L = 0, 2$ to a single $S$-wave six-quark state $|s^6 + 2\pi\rangle$ (see Eq.(7)). The increase of $\Lambda_{\pi NN}$ up to a value 0.8 GeV (with keeping the best fit to the phase shifts) results in the violation of the above condition and in a significant deterioration of the description of $\varepsilon_1$ (the dot-dashed curve in the lower right panel of Fig. 2).

Another important result of the present model could be a possible resolution of a long-standing puzzle about the small vector-meson contribution in single-baryon spectra and a strong spin-orbital splitting (due to the vector meson contribution) in the $NN$ interaction. Our explanation of the puzzle is based on the fact that there is no significant vector-meson contribution to $qq$ force (in $t$-channel) but there is an important contribution of vector mesons in dressing the symmetric six-quark bag leading thereby to strong spin-orbital effects in the $NN$ interaction mediated by the ”dressed” bag. Moreover, the proposed model will lead to the appearance of strong $3N$ and $4N$ forces mediated by $2\pi$ and $\rho$ exchanges [4]. The new $3N$ forces include both central and spin-orbit components. Such a spin-orbit $3N$ force is extremely desirable to explain the low energy puzzle of the analyzing power $A_y$ in $N-d$ scattering and also the behavior of $A_y$ in the $3N$ system at higher energies $E_N \simeq 250 \div 350$ MeV at backward angles [4]. The central components of the $3N$ and $4N$ forces are expected to be strongly attractive and thus they must contribute to $3N$ and (may be) $4N$ binding energies possibly resolving hereby the very old puzzle with the binding energies of the lightest nuclei.

To conclude: In this work we presented a new mechanism for the description of the intermediate- and short-range $NN$ interaction. The mechanism is distinguished from the traditional Yukawa concept of meson exchange in the $t$-channel. Instead of this, we introduce here a concept of the dressed symmetric six-quark bag in the intermediate state with $s$-channel propagation. The new interaction mechanism proposed here has been shown to lead to separable energy-dependent $s$-channel interaction with nodal form factors
which reflect the orthogonality of six-quark configurations in the initial $NN$ channel and the intermediate bag-like state.

Using a simple illustrative model we found that it is possible to give a good description of all the lowest $NN$ phase shifts in a large energy interval $0 \div 600$ MeV. This suggests strongly that the new microscopic mechanism of $s$-channel ”dressed” symmetric bag should work adequately. The model gives a natural microscopic background for previous semi-phenomenological models like the Moscow $NN$ potential, the Tabakin separable potential ”with attraction and repulsion” and also the QCB model by Simonov and other hybrid models. The significant enhancement of $\sigma$- and $\rho$-meson fields around the symmetric six-quark bag may also contributes to an explanation of ABC puzzle alternative to that assumed today. Future studies will show to what degree such expectations can be justified.

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**Figure captions**

**Fig. 1.** The graph illustrates the mechanism of $NN$ interaction via two sequential $\pi$-meson emissions and absorptions via an intermediate $\sigma$- (or $\rho$-) meson and the generation of a dressed six-quark bag $DB = s^6 + \sigma(\rho)$ in $NN$ scattering.

**Fig. 2.** The $NN$ phase shifts (in deg.) as predicted by our illustrative model in comparison with PSA data (SAID, solution SP99). The mixing parameter $\varepsilon_1$ for different values of cut-off parameter $\Lambda_{\pi NN}$ is displayed in the lower right corner (for explanations see the text).
FIGURES

FIG. 1.
FIG. 2.