acta phys. slov. 43 (1993), No. 6, 387–402

LOW ENERGY NN SCATTERING WITH COUPLINGS PREDICTED BY RELATIVISTICALLY INVARIANT QUARK MODEL

R. Antalík [1]

Institute of Physics, Slovak Academy of Sciences
Dúbravská cesta 9, 842 28 Bratislava, Slovakia

V.E. Lyubovitskij

Department of Physics, Tomsk State University,
Tomsk, Russia

Received 15 July 1993
Accepted 8 September 1993

The two-nucleon scattering momentum space OBE model is constructed starting from the π, ρ, η, η', ω, a_0, and ϵ meson-nucleon coupling constants, which we obtained within a relativistic quark confinement model. Working within the Blankenbecler-Sugar quasipotential dynamics we thus describe the NN phase shifts in a fully relativistic way. In this procedure we use the phenomenological form factor masses, and the effective ϵ and ω meson coupling constants, only. The resulting NN phase shifts are in good agreement with the empirical data and with the predictions of the conventional Bonn OBEP model.

I. INTRODUCTION

One of the fundamental problems in physics concerns the structure and interactions of hadrons in terms of their elementary quark and gluon constituents. Hovewer, at low energies and small momenta, the traditional description of nuclear forces and nuclear dynamics based on nucleon and meson degrees of freedom appear to give a viable phenomenology of nuclear reactions and structure [1]. At higher energies and momenta the hadronic degrees of freedom are gradually replaced by constituent ones. In such transitional domain different approaches that combine hadron and constituent exchanges are to be used, see [2, 3].

Phenomenologically are nuclear forces in a low energy domain well understood in terms of meson exchanges. Their long-range component, for the first time introduced by Yukawa [4], is generated by a pion exchange. The intermediate-range

[1] E-mail address: ANTALIK@SAVBA.SK

attraction between two-nucleons can be understood in terms of a correlated two pion exchange, usually simulated by a scalar-isoscalar ε meson. A repulsive ω meson exchange represents the short-range component of two-nucleon forces and the ρ exchange is notably distinctive in the isovector-tensor channel, where it reduces most of the corresponding pion tensor strength. In such one-boson-exchange (OBE) model approach, meson-nucleon coupling constants and form factor cutoffs represent physical parameters, which are to be determined from the best description of the NN scattering data. The conventional relativistically invariant interpretation of the experimental NN phase shifts regularly use such model of NN forces, see refs. [1, 5, 6, 7].

In this paper we investigate a possibility to understand the NN scattering problem starting from a relativistically invariant quark confinement model (QCM) developed at Dubna by Efimov, Ivanov and one of us (V.L.) [8, 9, 10]. Constructing an OBE model we consider a minimally possible collection of exchanged mesons. Doing this we use our predictions of meson-nucleon coupling constants that we obtain within the QCM [10, 11]. The form factors we treat but as is usual in a conventional interpretation scheme [1, 5], i.e., we choose their cutoffs to fit the NN phase shifts. This would be considered as justified because of the medium renormalization of meson and nucleon parameters, see, e.g. ref. [12].

A part of our interpretation scenario the QCM represents a relativistically invariant effective quantum field theory variant inferred from QCD. Within this scheme are hadrons treated as composed of quarks. The confinement of quarks emerges as in the QCD through nonperturbative gluon vacuum fields. There is no attempt in this model to evaluate the quark confinement but the S-matrix integration measure itself is conveniently parameterized. This parameterization then allows us to evaluate all quark diagrams representing the meson nucleon interactions. The processes investigated within this model approach cover the static hadron characteristics, the strong, electromagnetic, and weak dynamical properties of nonflavored, charmed, and bottom mesons and baryons [9, 10, 13]. In all these studies the acceptable results have been obtained. All this shows that the physical picture behind the QCM represents, although in the parameterized but unique way, the bulk properties of the hadronic structures. Our previous NN scattering studies are published in Ref. [14].

In section 2, we will briefly specify the the quasipotential dynamics and the meson exchange model of the NN interaction we used here. In section 3, we will briefly describe a formulation of the QCM, the meson-nucleon coupling constants calculation within its frame and its parameterization. In section 4, we present our results and discuss them. Section 5 is devoted to a summary and concluding remarks.

II. CONVENTIONAL INTERPRETATION SCHEME

To describe the scattering process we work in the framework of the three-dimensional quasipotential dynamics using the Blankenbecler-Sugar equation [1]. This equation can be written for the R-matrix, which is directly related to the NN phase shifts. It can be written as [15]

$$R = V + \mathcal{P} \int \frac{m\, d\mathbf{k}}{\mathbf{q}^2 - \mathbf{k}^2} V R \,, \tag{1}$$

where $\mathcal{P}$ denotes the principal value, and m is the nucleon mass. The amplitudes V represent the sum of all connected two-particle irreducible diagrams.

It is widely accepted [1, 5] that conventional one boson exchange model of NN forces is capable to describe the scattering observables. The NN forces are then given as a sum of the contributions of relevant mesons

$$V = \sum_{\alpha=\pi,\rho,\eta,\omega,a_0,\varepsilon} V_\alpha . \tag{2}$$

As the empirical findings show that to describe the low energy NN scattering the pseudoscalar, vector, and scalar meson fields need to be accounted for [1].

In the field theoretical language are meson-nucleon couplings described by the following relativistically invariant Lagrangians for pseudoscalar $\phi^{(ps)}$, scalar $\phi^{(s)}$ and vector $\phi^{(v)}$ meson interactions

$$\mathcal{L}_{ps} = i\sqrt{4\pi}\, g_{ps}\, \bar\psi\gamma^5\psi\phi^{(ps)} \,, \tag{3}$$

$$\mathcal{L}_{s} = i\sqrt{4\pi}\, g_{s}\, \bar\psi\psi\phi^{(s)} \,, \tag{4}$$

$$\mathcal{L}_{v} = i\sqrt{4\pi}\, g_{v}\, \bar\psi\gamma_\mu\psi\phi^{(v)}_\mu + i\sqrt{4\pi}\, \frac{f_v}{4M}\, \bar\psi\sigma^{\mu\nu}\psi(\partial_\mu\phi^{(v)}_\nu - \partial_\nu\phi^{(v)}_\mu) \,, \tag{5}$$

where g and f describe the vector and tensor couplings, ψ and $\bar\psi$ denote the nucleon field and its adjoint operators, respectively. For the exchange of isovector mesons $\phi^{(\alpha)}$ is replaced by $\tau \cdot \phi^{(\alpha)}$, where τ is the isotopic spin operator. Using Feynman techniques one can obtain the one boson exchange amplitudes for a particular mesonic field. The pseudoscalar, scalar, and vector meson amplitudes that we need for evaluation of the Blankenbecler-Sugar equation in its R-matrix form (1) are explicitly shown in ref. [16]. The form factors applied at each vertex are taken as

$$F_\alpha(\Delta^2) = \left(\frac{\Lambda_\alpha^2}{\Lambda_\alpha^2 - \Delta^2}\right) , \tag{6}$$

where Λ_α is the cutoff mass for α meson-nucleon vertex and $\Delta^2 = (E_{q'} - E_q)^2 - (\mathbf{q}' - \mathbf{q})^2$ is the four-momentum of the exchanged particle [15].

III. QCM CALCULATION OF MESON-NUCLEON COUPLING CONSTANTS

III.1. Quark Confinement Model

The meson-nucleon (in general the meson baryon) interaction vertex is within the quark model represented by the Feynman diagram shown in Fig. 1. The quark-hadron vertex is in the quark model described by the interaction Lagrangians of the form [8, 9, 10]

$$\mathcal{L}_H(x) = g_H\; H(x)\; J_H(x)\,, \tag{7}$$

where $J_H(x)$ are quark currents with the quantum numbers corresponding to the considered hadronic field $H(x)$. The renormalized coupling constant g_H can be obtained from the following compositeness condition

$$Z_H = 1 + \frac{3g_H^2}{(2\pi)^2}\,\tilde{\Pi}'_H(m_H^2) = 0\,, \tag{8}$$

where $\tilde{\Pi}'_H$ is the derivative of the hadronic mass operator.

Let us specify the actual Lagrangian for both types of vertices we have in Fig. 1, i.e. the quark-meson vertex, and the quark-baryon vertices. The quark-meson interaction Lagrangian reads

$$\mathcal{L}_M = \frac{g_M}{\sqrt{2}} \sum_{i=1}^{8} M_i\; \bar{q}\,\Gamma_M\; \lambda_i\; q\,, \tag{9}$$

where $q, \bar{q}$ are the quark, antiquark meson constituting fields, $\bar{q} = (\bar{u}, \bar{d}, \bar{s})$, M_i are the Euclidean mesonic fields relating to the physical mesons in the standard way [10], λ_i are the Gell-Mann matrices, and Γ_M stands instead of $i\gamma^5$ for pseudoscalar mesons $P(\pi, \eta, \eta')$, γ^μ for vector mesons $V(\rho, \omega, \phi)$, and $(I - iH_S\hat{\partial}/\Lambda_q)$ for scalar mesons $S(a_0, f_0, \sigma)$. Because of SU(3) breaking, the singlet and octet mesons are mixed as follows

$$(\eta', \omega, \varepsilon) \rightarrow \cos\delta_\Gamma \left(\frac{\bar{u}u + \bar{d}d}{\sqrt{2}}\right) - (\bar{s}s)\sin\delta_\Gamma\,,$$
$$(\eta, \phi, f_0) \rightarrow -\sin\delta_\Gamma \left(\frac{\bar{u}u + \bar{d}d}{\sqrt{2}}\right) - (\bar{s}s)\cos\delta_\Gamma\,, \tag{10}$$

where $\delta_\Gamma = \theta_\Gamma - \theta_{I\Gamma}$, and $\theta_{I\Gamma} = 35^\circ$ is the so-called ideal mixing angle. The mixing angles of pseudoscalar and vector mesons are chosen to be equal to $\delta_P = -46^\circ$ and $\delta_V = 0^\circ$, respectively. The scalar meson parameters δ_S, H_S and m_ε are supposed to be free. Their determination we will comment on later.

The SU(3) quark currents with baryon quantum numbers have to be symmetric in respect to the quark field permutation. Since, for the $(1/2)^+$ baryonic octet there are two independent three-quark currents, the quark-baryon interaction Lagrangians read

$$\begin{aligned} \mathcal{L}_B &= \mathcal{L}_{BT} + \mathcal{L}_{BV}\,, \\ \mathcal{L}_{BI} &= g_{BI}\; \bar{B}\; J_{BI} \\ &= ig_{BI}\; \bar{B}_j^k\; R_I^{kj;j_1j_2j_3}\; q_{j_1}^{a_1} q_{j_2}^{a_2} q_{j_3}^{a_3}\; \varepsilon^{a_1a_2a_3} + H.c. \end{aligned} \tag{11}$$

In these expressions $j = (\alpha, m)$; and (a_i, α_h, m_i) are the colour, spin, and flavour indices, respectively. B_j^k are the Euclidean baryonic fields, and matrices $R_I^{kjj_1j_2j_3}$

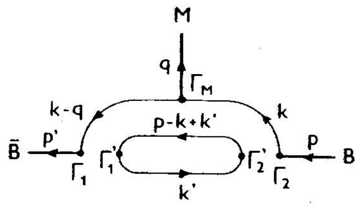

Fig. 1. The meson – three-quark baryon vertex diagram

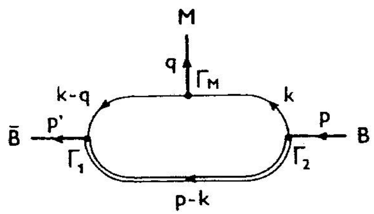

Fig. 2. The meson – quark-diquark baryon vertex diagram.

provide proper quark content of the baryons in the vector or tensor coupling scheme, $I = V, T$.

The meson-nucleon interaction is in a quark model represented through the diagram as in Fig. 1. The typical matrix element corresponding to the process $B \rightarrow B + M$ is proportional to the following expression

$$\begin{aligned} &\int d\sigma_{vac}\; \bar{B}(x_1)\; S(x_1x_3|B_{vac})\; M(x_3)\; S(x_3x_2|B_{vac})\; B(x_2) \\ &\cdot \int d\sigma_{vac'}\; Tr[S(x_1x_2|B_{vac'})\; S(x_2x_1|B_{vac'})]\,, \end{aligned} \tag{12}$$

where $S(x, x'|B_{vac})$ denotes the quark propagator in the external gluon field B_{vac}, and $d\sigma_{vac}$ is the measure of integration over B_{vac}. This highly complex gluon vacuum is supposed to provide quark confinement itself within QCD.

To proceed in evaluation of the expression (12) we make use of the QCM method. The cornerstone of this effective field theory is a prescription for parameterization of the confinement producing gluon vacuum fields [8, 9]. This means that the expression (12) is substituted by the following one:

$$\begin{aligned} &\int d\sigma_v\; \bar{B}(x_1)\; S_v(x_1 - x_3)\; M(x_3)\; S_v(x_3 - x_2)\; B(x_2) \\ &\cdot \int d\sigma_{v'}\; Tr[S_{v'}(x_1 - x_2)\; S_{v'}(x_2 - x_1)]\,, \end{aligned} \tag{13}$$

which is the QCM ansatz [8, 9]. In this expression

$$S_v(x_1 - x_2) = \int \frac{d^4p}{(2\pi)^4 i} \frac{e^{-ip(x_1-x_2)}}{v\Lambda_q - \hat{p}} \qquad (14)$$

is the quark field propagator weighted by the quark confining field parameter v. The model parameter Λ_q determine the confinement range. The indefinite measure $d\sigma_v$ in (13) is defined as

$$\int \frac{d\sigma_v}{v - z} = G(z) = a(-z^2) + zb(-z^2) . \qquad (15)$$

The function $G(z)$, the so-called confinement function, is the entire analytical function that decreases faster than any degree of z in the Euclidean direction $z^2 \to -\infty$. This requirement let us a possibility to construct a finite theory with confined quarks. Note that these requirements are very general, and as the result there is a possibility to choose of various actual forms of $G(z)$. The confinement function is taken as universal, i.e., it is colour, and flavour independent, and unique for all quark diagrams determining hadron interactions. As experience has shown, the only its integral characteristics are important for description of the low-energy physics.

To simplify the calculations of the Feynman diagram in Fig. 1, one can substitute the inner two-quark loop by the single propagator, the so-called diquark propagator, ref. [10]. The meson baryon vertex of Fig. 1 will then be redrawn to that one shown in Fig. 2. This means that the subdiagram corresponding to the independent two-quark loop

$$\Pi^{\Gamma_1\Gamma_2}(p) = \int \frac{d^4k}{4\pi^2 i} \int d\sigma_{v'}\, Tr[\Gamma_1' \, S_{v'}(p+k)\, \Gamma_2' \, S_{v'}(k)] \qquad (16)$$

is substituted by the diquark propagator $D^{\Gamma_1\Gamma_2}$

$$D^{\Gamma_1\Gamma_2}(k) = \frac{d^{\Gamma_1\Gamma_2}}{M_D^2 - k^2} , \qquad (17)$$

where M_D is a diquark mass, and $d^{\Gamma_1\Gamma_2}$ are coefficients dictated by the symmetry properties. This approximation should fulfill the general requirement - not to break the relation between the baryon electromagnetic vertex and the mass operator, the Ward identity. This identity with the compositeness condition (8) give us needed symmetry properties, see ref. [10].

Consider the last approximation (16), the meson baryon vertex may be written in the form

$$\Lambda_{MNN}(p,p',q) = \int \frac{d^4k}{\pi^2 i} \int d\sigma_v \cdot \Gamma_1 \frac{1}{v\Lambda_q - (\hat{k} - \hat{q})} \Gamma_M \frac{1}{v\Lambda_q - \hat{k}} \frac{d^{\Gamma_1\Gamma_2}}{M_D^2 - (p-k)^2} \Gamma_2 \qquad (18)$$

which can be evaluated by using the standard Feynman method. Finally, the transfered momentum dependent meson-nucleon coupling constants are related to this vertex function as

$$\Lambda_{MNN}(p,p',0) = T_M\, G_{MNN} , \qquad (19)$$

where $T_\pi = \vec{\tau} i\gamma^5$, $T_\eta = T_\eta' = I i\gamma^5$, $T_{a_0} = \vec{\tau}$, $T_\varepsilon = I$, for pseudoscalar and scalar mesons, respectively, and in terms of the vector and tensor form factors

$$\Lambda^\mu_{MNN}(p,p',0) = T_M\, [\gamma^\mu G_{MNN} - i\sigma^{\mu\nu} q_\nu F_{MNN}] , \qquad (20)$$

where $T_\rho = \vec{\tau}$, $T_\omega = I$ for vector mesons. The vector, and tensor meson-nucleon coupling constants are the $G_{MNN}(q^2)$, and $F_{MNN}(q^2)$ taken at zero transfered momentum, i.e. $q^2 = 0$, respectively.

III.2 QCM parameterization

Free parameters of the present QCM version are the parameters of the confinement ansatz, the parameters of the quark-meson interaction Lagrangian, and the diquark propagator parameters. The confinement ansatz (13-15) free parameters are the coefficients of the confinement functions $a(u)$, $b(u)$ and the light quark confinement parameter Λ_q.

As follows from the confinement ansatz (13, 15), the confinement functions $a(u)$ and $b(u)$ should be entire analytical functions decreasing sufficiently rapidly in the Euclidean region $Re(u) \to \infty$. In this paper we take these functions in the simplest forms

$$a(u) = a_0\, exp(-u^2 - a_1 u) , \qquad (21)$$
$$b(u) = b_0\, exp(-u^2 + b_1 u) . \qquad (22)$$

These coefficients (a_0, a_1, b_0, b_1), and other confinement ansatz free parameters, have been obtained by the fitting of a convenient set of reference observables [11]. This chosen set of the reference hadronic processes, and fitted the QCM values with the empirical results are shown in table 1. These results have been obtained with the confinement ansatz parameters shown in table 2.

Table 1. Reference hadronic processes

Process	Observable value	Ref[31]	QCM
$\pi \to \mu\nu$	f_π (MeV)	132	131
$\rho \to \gamma$	$g_{\rho\gamma}$	0.20	0.18
$\pi^0 \to \gamma\gamma$	$g_{\pi\gamma\gamma}$ (GeV^{-1})	0.276	0.287
$\omega \to \pi\gamma$	$g_{\omega\pi\gamma}$ (GeV^{-1})	2.54	2.02
$\rho \to \pi\pi$	$g_{\rho\pi\pi}$	6.1	6.5
$p \to p\gamma$	μ_p	2.793	2.798
$n \to n\gamma$	μ_n	-1.913	-1.864

Table 2. QCM parameters

a_0	b_0	a_1	b_1	$\Lambda_q(MeV)$	$M_D(MeV)$	C_{VT}	H_s	δ_s	m_s
1.5	2.0	[illegible]	0.2	400	670	1	0.55	17	600

As stated above the quark-meson interaction Lagrangian (9) has its free parameters only in the scalar meson sector. These are the derivative term strength H_S, and the mixing angle value δ_S. Both parameters have been determined and thoroughly discussed in ref. [9]. The last free parameters of the present QCM version are the parameters of the diquark propagator (17), namely M_D – a diquark mass, and $d^{\Gamma_1\Gamma_2}$ – diquark symmetry coefficients. These have been determined and used to predict numerous characteristics of hadrons and hadronic processes as magnetic moments of baryons, weak coupling constants, and various decay widths with rather good resuls in ref. [11]. Both the diquark mass M_D and the diquark coefficient C_{VT} are also shown in table 2. It should be noted that in fact the work [11] is a reinvestigation of the same physics as have been studied in the paper [10] using but the different constant-mass form for the diquark propagator. The application of such form of the diquark propagator has been motivated by the success of the bottom mesons decay studies, where for a heavy-quark propagator the constant-mass propagator has been used.

As one can see in refs. [9, 10, 13] generally good assessments of the strong, electromagnetic, and weak interactions controlled processes have been acquired within the QCM. It should be said further that after preceding steps we have the effective quark field theory with ***any free parameters.***

IV. RESULTS AND DISCUSSION

Despite of the fact that the one boson exchange model is a simplified representation of the NN forces, the effectiveness of this approach is at least at low-energies established, see, e.g. ref. [17]. The strong intermediate-range attraction and the strong short-range repulsion pose some questions as concerning their microscopic understanding. Within OBE models are these NN force properties described by using the ε and ω mesons, for a description of the attractive and repulsive parts, respectively. Many studies have been devoted to elaborate understanding of the intermediate-range attraction. The studies performed with using a dispersion relation technique conclude [18] that a major part of this attraction arises from the correlated two-pion exchanges, which are in turn well approximated by the exchange of the ε meson. Similarly, as it has been shown by the Bonn group [16] within their full meson exchange model, more complex non-iterative $\pi\rho$ exchange diagrams are well approximated by the ε meson. For discussion of the ε meson itself see also very recent development by the Brooklyn group [19]. The new information arises also from a development by Weinberg and others [20], who have recently use a chiral perturbation theory to study the nature of the NN forces. A satisfying qualitative feature, which they have found shows that the uncorrelated two-pion exchange with some of the higher order contact terms provide the intermediate-range attraction.

The understanding of the processes that cause the high value of the OBE ω meson coupling constant also advanced recently [2, 3]. It is known qualitatively that this short-range repulsive meson exchange simulates partially forces originating in the quark-gluon exchange processes and possibly by exchange of heavier vector meson fields also. As Faessler discusses [3] his calculations can easily accommodate a repulsive ω exchange using the ωNN coupling compatible with the SU(3) value, i.e., the coupling constant of the value around 4. From this discussion we can see that within an OBE model we use at least two-mesons, which simulate more complex processes also. Consequently, their couplings cannot be the bare couplings as that ones calculated within quark models. Such couplings should be but the effective ones, because they in fact represent both the complex hadron constituent and the complex meson exchanges. Bearing this in mind, we can go on discussing our results.

In the present paper we take as a set of exchanged mesonic fields all mesons with their masses under 1 GeV. Note that this is a standard choice within the conventional interpretation scheme [1, 5, 16]. Accordingly, our set of the mesonic fields consists of the $\pi, \rho, \eta, \eta', \omega, a_0$ and ε meson fields. The $f_0(975)$ meson we do not include in this work because of its coupling constant predicted by the present parameterization of the QCM is very small, about 0.2. The QCM predictions of the meson-nucleon coupling constants, are displayed in table 3. Some of the coupling constants shown in table 3 are connected by the SU(3) symmetry relations. These are the vector couplings for the ρ and ω vector mesons. Further, the ratio of the vector meson tensor to vector coupling constant is $\kappa_v = f_{vNN}/g_{vNN} = \mu_p - \mu_n - 1$. Although in the present work we will not use the QCM predictions of the meson-nucleon form factors we have to notice the following. Parameterizing the low transferred momenta part of the meson-nucleon form factors by the monopole forms we find that they cutoffs have the values lower than 1 GeV, as expected from the hadronic root mean square radii, and which is in an agreement with other sources, see, e.g. [2, 3, 21].

Table 3. The QCM predictions of the meson-nucleon coupling constants, and the QRBA7 OBE parameters. Numbers in bold face were varied during the fitting procedure.

	QCM	QRBA7	
Vertex	$g^2/4\pi$ (f/g)	$g^2/4\pi$ (f/g)	Λ (MeV)
πNN	13.85	13.85	**2099**
ηNN	3.858	3.858	**1000**
η' NN	3.065	3.065	**1000**
ρNN	0.416 (3.66)	0.416 (3.66)	**1442**
ωNN	3.740 (-0.07)	**15.40(0.20)**	2000
εNN	3.620	**10.17**	2000
a_0NN	1.996	1.996	**1800**

The construction of our OBE QRBA7 (Quark Relativistic Bosons version A with 7 exchanged fields) model we start out from our QCM predictions of the meson-nucleon coupling constants and typical cutoff masses [5] of the phenomenological form factors (6). Because of the above specified reasons connected with the effectiveness of ε and ω exchanges, we first optimize the εNN and ωNN coupling constants. Afterward, we include to optimization process also the form factor cutoff masses. Using ω meson as the effective exchanged field we allow to vary its tensor component also. Parameters of the resulting QRBA7 OBE model are also shown in table 3. Concerning the parameter determination procedure the following should be said. As the empirical data we take the phase shift values obtained by Arndt at al. [22]. We minimize the χ^2 criterion as determined by using diagonal phase shift uncertainties only. The fitting we span over up to 450 MeV of the laboratory energy. From a physical viewpoint this may be done because the imaginary parts of the phase shifts in all partial waves are small, except the $^1D_2$ and $^3F_3$ waves, in this energy region [1].

Our phase shift predictions are shown in Figures 3-4. The predictions are compared there to empirical data and to a phenomenological fit. The referred empirical data are that we used in fitting procedure [22]. The results of the mentioned phenomenological fit we have calculated from Bonn OBE(B) model [5], commonly regarded as a standard one. Note that this OBE model is affirmed to 325 MeV of the laboratory energy only. As seen, our predictions well agree with the empirical data. To quantify this statement we may say that the ratio of the χ^2 criterions we have obtained with QRBA7 model to that one obtained with the Bonn OBE(B) model [5], is 1.6 (both values we have calculated with the same referred empirical data set [22]). Notice that as it has been shown by Lomon [23], the couplings to the isobar channels are responsible for the resonant behaviour of the $^1D_2$ and $^3F_3$ phase shifts, thus we do not show their here.

Concerning the phase shift results we would like to comment only on the behaviour of the $^3S_1 - ^3D_1$ mixing parameter ϵ_1. In a recent phase shift analysis in which the Basel group has used their newly measured spin correlation parameter from a neutron-proton scattering they obtain the value of $\epsilon_1 = 2.9^0(\pm 0.3^0)$ at 50 MeV [24]. The another analysis [25], which includes also the Basel data reports the value $\epsilon_1 = 2.2^0(\pm 0.5^0)$ for the same energy. This last value is in agreement with both theoretical values shown in Fig. 1.

Table 4. Comparison of the present QRBA7 meson-nucleon coupling constants with the Bonn^M OBE(B) version [5], the Bonn^H [32], and Nijmegen [6] are shown (f is a tensor coupling constant; all at 0 transfered momenta). ^{a} used for T=1 channels.

Vertex	QRBA7 $g^2/4\pi$ (f)	Bonn^M $g^2/4\pi$ (f)	Bonn^H $g^2/4\pi$ (f)	Nijmegen $g^2/4\pi$ (f)
π NN	13.85	14.21	14.17	13.40
η NN	3.858	2.25	4.56	2.48
η'NN	3.065	–	–	1.403
a_0NN	1.996	1.43	1.83	0.64
ϵNN	10.17	7.51^a	6.22^a	12.22
ωNN	15.40 (2.78)	11.13	9.25	4.49 (2.50)
ρNN	0.416 (8.37)	0.42 (14.0)	0.37 (14.2)	0.42 (9.70)

Now we compare the meson-nucleon coupling constants of our QRBA7 OBE model and thus the QCM predictions, except ϵNN and ωNN couplings, with couplings from other studies. In table 4, we display parameters of the present QRBA7 OBE model together with the OBE parameters as they have been obtained by two

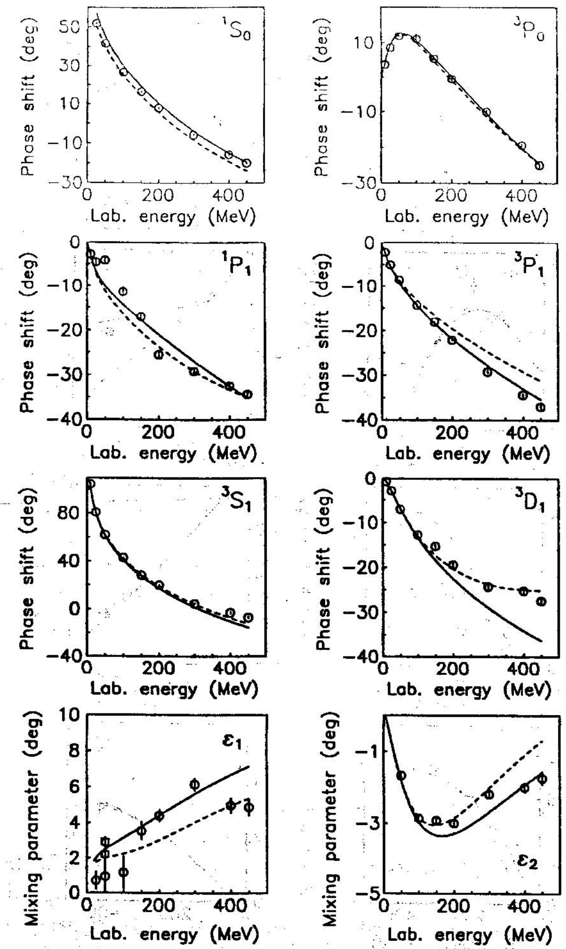

Fig. 3. The phase shifts of the NN scattering. The solid lines represent the results obtained with the QRBA7 parameters. The dashed lines refer to the results we calculate with the OBE(B) parameter set [5]. The experimental data (circles) are that of Arndt et al. [22]. The squares in ϵ_1 mixing parameter are results of the Basel [24] and Nijmegen [25] analyses, the upper and lower value, respectively.

leading groups in low-energy NN scattering phenomenology, namely the Bonn and Nijmegen groups. A recent warm discussion [26, 27] about the πNN coupling constant has appeared thanks to the analysis of new πN scattering data by Arndt et al. [28]. In this work the VPI&SU group has estimated the charged-pion coupling constant to be 13.31($\pm$0.27), confirming thus the older results of the Nijmegen

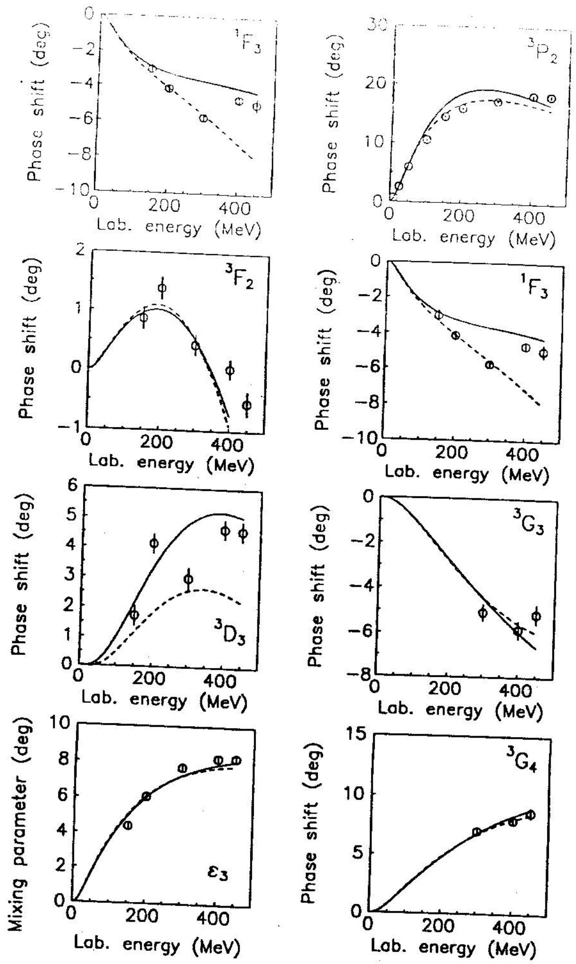

Fig. 4. The phase shifts of the NN scattering. For description see caption to Fig.3.

group, see ref. [27] and references therein. Problems arise because this new value of the πNN coupling is much under the coupling constant value commonly used for more than a decade, namely 14.3($\pm$0.2), see, refs. [29, 30, 5]. One should mention perhaps that the Goldberger-Treiman relation [31] gives the pion-nucleon coupling constant to be equal 13.0. As one can see from the table 4, where are all couplings shown for zero transferred momentum, the present QCM parameterization predicts the πNN coupling constant value, which is in the middle of the both Nijmegen and Bonn boundaries shown there.

Concerning our value of the η meson-nucleon coupling is also in the middle of the corresponding Bonn values. The η' meson we should include to be consistent

from a quark model point of view, where η and η' are formed in pseudoscalar octet-singlet mixing [31]. Both the ηNN and η'NN couplings are but significantly lower than our values. Comparing by the QCM predicted a_0NN coupling constant to phenomenological values obtained in NN scattering fit, we find that our value is approximately the same as in the Bonn model [32], about one third higher than that one fitted in [5], but the three times of the Nijmegen value [6].

Since in the present model we use the only one exchanged scalar-isoscalar meson it has to serve as the effective intermediate-range attraction simulating field. Consequently, the constraint on its coupling constant requires of it to has a reasonable value and to be in a strong correlation with the value of the short-range repulsive strength. As seen from table 4, its value is nearly two third of the ωNN coupling, which is comparable to the both Bonn models. The same, is viceversa true for the effective ω vector meson-nucleon coupling. A note is needed concerning the small ωNN vector coupling in the Nijmegen model. An additional short-range repulsion in that model brings forth the additional Pomeron exchange and so relations mentioned above are not so simple there. In a present model we suppose that the ω exchange generates also a tensor force, as it is in the Nijmegen and in other models, e.g. [17]. This we will discuss with the ρ meson exchange.

The value of the ρ vector meson-nucleon coupling, as seen in table 4, is in a good agreement with standard couplings. The size of the tensor coupling constant used in OBE models have relied on the old analysis of ref. [29]. In that paper the value of $\kappa_\rho = 6.1(\pm 0.6)$ was obtained for a ratio of the tensor to vector coupling constants. This value, which has been used also by the Bonn group, lead them to the values of the ρ meson-nucleon tensor coupling constants shown in table 4 ($\kappa_\rho =$ 6.1 in [5] and $\kappa_\rho = 6.6$ in [32]). Such high values of the κ_ρ lead them in conjunction with the high values of the πNN couplings to the conclusion that the effective ωNN tensor coupling is consistent with zero. It is known but empirically for a long time the κ_ρ has to be consistent with the empirical value following from a vector meson dominance of a low momentum part of the nucleon electromagnetic form factor. This empirical value $\kappa_\rho = 3.7$ [1] is consistent with our QCM predicted value $\kappa_\rho =$ 3.66. The Nijmegen model value is $\kappa_\rho = 4.221$.

As we suppose in the QRBA7 model, the effective ω exchange generates a tensor force as the Nijmegen and other models does also. The inspection in table 4, where are the tensor coupling constants displaied shows that the both mentioned models have almost the same amount of the tensor force ($\kappa_\omega = 0.20$ in present work and $\kappa_\omega = 0.333$ in [6]). These results are in good agreement with the amount of the tensor force that has been obtained in a nucleon form factor study [29], namely $\kappa_\omega \leq 0.2$. Further, the sums of the both the ρNN and ωNN tensor couplings of the QRBA7 or Nijmegen models are roughly compatible with the both Bonn tensor ρNN couplings. The QCM prediction of the bare tensor force is κ_ω = -0.07 (table 3). Notice that the identical result have been obtained by Kaiser et al. [21] within a complete version of their chiral soliton model. This value is compatible with the empirical value (-0.12) [1].

A form factor problem in NN scattering is up to now far from being settled in a low energy domain. First, as we mentioned in sect. 1, an expected medium renormalization changes the meson and nucleon parameters [12]. Representing but the NN scattering problem it is insufficient to have only fully renormalized vertices, as we have in the QCM. In a theoretically correct representation the exchanged meson propagator has to be also renormalized. Second, as known, and as it has been recently calculated in refs. [21, 33], the meson-nucleon interaction is density dependent. Whether this density dependence of a bare meson-nucleon system is effective enough to modify the low energy NN scattering is a priori not known. Further, it is known that the cutoff masses depend also, and as seems mostly on a type of used relativistic equations (to observe this one can intercompare OBE parameters shown in tables A.1 and A.2 of the ref. [5]) and on a chosen spectrum of exchanged particles (compare, e.g., different OBE models of the ref. [17]). Moreover, it seems that the phenomenological form factors should be treated as it has been shown by Gross and collaborators [17]. Thus the reliable values of the cutoff masses are hard to determine in the NN scattering now. Therefore, in the present work we are not to solve this problem but rather we parameterize it.

Within the present environment, composed of the Blankenbecler-Sugar equation and the QRBA7 OBE model, most of used cutoffs are not very certainly determined. The cutoff masses of the η, η' and a_0 mesons may be changed in a wide interval of values without a significant deterioration of the fit quality. The πNN and ρNN vertex cutoffs are on the other hand determined strictly with their correlation measuring -97%.

Although we do not apply the QCM predicted cutoffs here it is of specific interest to compare these especially for critical meson-nucleon couplings, namely for the πNN and ρNN vertices. The QCM predicts for Λ_π and Λ_ρ the values of 880 and 600 MeV, respectively. These predictions may be compared to the results of a non-linear chiral meson theory of ref. [21], where the values obained for Λ_π and Λ_ρ are 860 and 930 MeV, respectively. Although the absolute values of the QCM are very different from the QRBA7 model values, table 3, we find that their ratio is 1.477 comparing to the QRBA7 value of 1.456. The mentioned density dependence of the form factor cutoffs, estimated in [21] for Λ_π and Λ_ρ, represents approximately 20 and 10% quenching at the nuclear density, respectively. On the other hand, a comparison of the QRBA7 cutoffs with the QCM ones shows that the former values are renormalized by a factor higher than two. Thus, it seems, the density dependence of the form factor cutoffs may be fully neglected here.

V. CONCLUSIONS

In this paper we have investigated the low energy part of the NN scattering relying on the empirical findings that the mesonic degrees of freedom represent a proper way to describe hadron scattering at this energy domain [1]. In this, we have constructed the one boson exchange model using the meson-nucleon coupling constants predictions of the QCM, a model deduced from the QCD. It is to be mentioned that it was not our intention to find a quantitatively competitive description of the NN scattering observables in the present work. Rather, we intend to find a way of obtaining the NN scattering predictions having a model parameterized on the quark level only, although it may not be achieved early, some guidance should be gathered gradually.

As seen from Figures 3 and 4 our phase shift predictions well agree with

the empirical data. The ratio of our χ^2 that we have obtained with the QRBA7 model to the χ^2 we have calculated for the Bonn model [5] is 1.6, what is the unexpectedly good result. The cutoff masses we take phenomenologically as is usual in a conventional model. The intermediate-range attraction and the repulsive short-range components of the NN forces we describe through the effective ε and ω exchanges. As important, however, we regard the fact that coupling constants of the other mesons are ***the parameter-free predictions of the QCM***.

In the present NN scattering description composed of the Blankenbecler-Sugar quasipotential equation and the QRBA7 OBE model, we find a standard value for the ratio of the effective intermediate-range attraction to the short-range repulsion. The η, η' and a_0 meson cutoffs are not very strongly restricted by the NN phase shifts predictions. The π and ρ meson cutoffs are strongly anticorrelated having but the ratio of their fitted cutoffs equal to the QCM predicted value. This may indicate that the present QRBA7 OBE model π meson exchange effectively simulate some other exchanges too or a big vacuum renormalization effect on its propagator is exhibited there. Thus we would try to find the reasons for the Λ_π value we find here.

Acknowledgements

The authors are indebted to G.V. Efimov, M.A. Ivanov and J. Lánik for many fruitful discussions. This work was partially supported by the Grant Agency of the Slovak Academy of Sciences under the grant GA-SAV-141/1993 and the grant GA-SAV-517/1993.

REFERENCES

[1] G.E. Brown, A.D. Jackson: *The nucleon-nucleon interaction*, North Holland, Amsterdam 1976
[2] F. Myhrer, J. Wroldsen: Rev. Mod. Phys. *60* (1988) 629
[3] A. Faessler: Prog. Part. Nucl. Phys. *13* (1985) 253; Thomas, A.W.: Adv. Nucl. Phys. *13* (1983) 1; Weise, W. ed.: *Quarks in Nuclei*. World Scientific, Singapore 1984
[4] H. Yukawa: Proc. Phys. Mat. Soc. 17 (1935) 48
[5] R. Machleidt: Adv. Nucl. Phys. *19* (1989) 189
[6] N.M. Nagels, T.A. Rijken, J.J. de Swart: Phys. Rev. *D17* (1978) 768
[7] M. Lacombe, B. Loiseau, J.M. Richard, R. Vinh Mau, J. Côté, P. Pirès, R. de Tourreil: Phys. Rev. *C21* (1980) 861
[8] G.V. Efimov, M.A. Ivanov: Int. J. Mod. Phys. A *4* (1989) 2031
[9] G.V. Efimov, M.A. Ivanov: Sov. J. Part. Nucl. *20* (1989) 479
[10] G.V. Efimov, M.A. Ivanov, V.E. Lyubovitskij: Z. Phys. C - Particles and Fields *47* (1990) 583
[11] G.V. Efimov, M.A. Ivanov, V.E. Lyubovitskij: Tomsk Scientific Center, Siberian Academy of Science, Preprint 41/90 (1990)
[12] D. Lurié: *Particles and Fields*, J. Wiley & Sons, New York 1968
[13] G.V. Efimov, M.A. Ivanov, N.B. Kulimanova, V.E. Lyubovitskij: Z. Phys. C - Particles and Fields *52* (1991) 129; G.V. Efimov, M.A. Ivanov, V.E. Lyubovitskij: Z. Phys. C - Particles and Fields *52* (1991) 149; M.A. Ivanov, T. Mizutani: Phys. Rev. *D45* (1992) 1580; M.A. Ivanov, O.E. Khomutenko, T. Mizutani: Phys. Rev. *D46* (1992) 3817

[14] R. Antalik, V.E. Lyubovitskij : Few-Body Systems, Suppl. 5 (1992) 464; R. Antalik, V.E. Lyubovitskij : Czech. J Phys. *43* (1993) 747
[15] K. Erkelenz, R. Alzetta, K. Holinde : Nucl. Phys. *A176* (1971) 413; K. Holinde, K. Erkelenz, R. Alzetta : Nucl. Phys. *A194* (1971) 161
[16] R. Machleidt, K. Holinde, Ch. Elster : Phys. Rep. *149* (1987) 1
[17] F. Gross, J.W. Van Orden, K. Holinde : Phys. Rev. *C45* (1992) 2094
[18] J.W. Durso, A.D. Jackson, B.J. Verwest : Nucl. Phys. *A282* (1977) 404; Nucl. Phys. *A345* (1980) 471; J.W. Durso, M. Saavela, G.E. Brown, A.D. Jackson : Nucl. Phys. *A278* (1977) 445
[19] L.S. Celenza, A. Pantziris, C.M. Shakin, J. Szweda : Brooklyn College Report: BCCNT 92/102/227 (1992); L.S. Celenza, C.M. Shakin, and J. Szweda: Brooklyn College Report: BCCNT 92/102/228 (1992)
[20] S. Weinberg : Phys. Lett. *B251* (1990) 288; Nucl. Phys. *B363* (1991) 3; C. Ordonez, U. van Kolck : Phys. Lett. *B291* (1992) 459
[21] U.-G. Meissner : Nucl. Phys. *A503* (1989) 801; N. Kaiser, U. Vogl, W. Weise, U.-G. Meissner : Nucl. Phys. *A484* (1988) 593
[22] R.A. Arndt, J.S. Hyslop, L.D. Roper : Phys. Rev. *D35* (1987) 128
[23] E.L. Lomon : Phys. Rev. *D26* (1982) 576
[24] M. Hammans, C. Brogly-Gysin, S. Burzynski, J. Campbell, P. Haffter, R. Henneck, W. Lorenzon, M.A. Pickar, I. Sick, J.A. Konter, S. Mango, B. van den Brandt : Phys. Rev. Lett. *66* (1991) 2293
[25] R.A.M. Klomp, V.G.J. Stoks, J.J. de Swart : Phys. Rev. *C45* (1992) 2023
[26] T.E.O. Ericson : Nucl. Phys. *A543* (1992) 409c
[27] V. Stoks, R. Timmermans, J.J. de Swart : Phys. Rev. *C47* (1993) 512
[28] R.A. Arndt, Z. Li, L.D. Roper, R.L. Workman : Phys. Rev. Lett. *65* (1990) 157; Phys. Rev. *D44* (1991) 289
[29] G. Höhler, E. Pietarinen : Nucl. Phys. *B95* (1975) 210; Nucl. Phys. *B114* (1976) 505
[30] R. Koch, E. Pietarinen : Nucl. Phys. *A336* (1980) 331
[31] Review of Particle Properties, Phys. Rev. *D45* (1992) No. 11, Part II
[32] K. Holinde : Phys. Rep. *68* (1981) 121
[33] Zhi-Xin Qian, Cheng-Gang Su, Ru-Keng Su : Phys. Rev. *C47* (1993) 877