RELATIVISTIC INTERACTIONS FOR MESON-NUCLEON SYSTEMS: APPLICATIONS IN THE THEORY OF NUCLEAR REACTIONS

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It is shown that the method of unitary clothing transformations (UCT) developed in [1, 2] and applied to nuclear physics problems [3, 4], gives a fresh look at constructing interactions between the "clothed" nucleons, these quasi-particles with the properties of physical nucleons.

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1. SOME RECOLLECTIONS

Our departure point is the Hamiltonian of a system of interacting mesons and nucleons that can be written as

$$H = \sum_{C=0}^{\infty} \sum_{A=0}^{\infty} H_{CA}, \tag{1}$$

$$H_{CA} = \sum\!\!\!\!\!\!\int H_{CA}(1', 2', ..., n'_C; 1,2,...,n_A) \times a^\dagger(1')a^\dagger(2')...a^\dagger(n'_C)a(n_A)...a(2)a(1), \tag{2}$$

where the capital $C(A)$ denotes particle-creation (annihilation) number for operator substructure H_{CA} and

$$\begin{aligned} &H_{CA}(1', ..., C; 1,..., A) \\ &= \delta(\vec{p}_1' + ... + \vec{p}_C' - \vec{p}_1 - ... - \vec{p}_A) \\ &\times h_{CA}(p_1'\mu_1'\xi_1' ... p_C'\mu_C'\xi_C'; p_1\mu_1\xi_1 ... p_A\mu_A\xi_A), \end{aligned} \tag{3}$$

where c-number coefficients h_{CA} do not contain delta function and $a^\dagger[a](n) = a^\dagger[a](\vec{p}_n, \mu_n, \xi_n)$ is a creation [annihilation] operator for particle of species ξ_n with momentum $\vec{p}_n$ and polarization μ_n.

In turn,

$$H_{CA} = \int H_{CA}(\vec{x})d\vec{x} \quad \Rightarrow \quad H = \int H(\vec{x})d\vec{x} \tag{4}$$

with density

$$H(\vec{x}) = \sum_{C=0}^{\infty} \sum_{A=0}^{\infty} H_{CA}(\vec{x}). \tag{5}$$

For example, in case with $C = A = 2$ we have

$$H_{22}(1', 2'; 1, 2) = \delta(\vec{p}_1' + \vec{p}_2' - \vec{p}_1 - \vec{p}_2)h(1'2'; 12) \tag{6}$$

and

$$H_{22}(\vec{x}) = \frac{1}{(2\pi)^3} \sum\!\!\!\!\!\!\int \exp[-i(\vec{p}_1' + \vec{p}_2' - \vec{p}_1 - \vec{p}_2)\vec{x}] \times h(1'2'; 12)a^\dagger(1')\, a^\dagger(2')\, a(2)\, a(1)\,. \tag{7}$$

The operator H, being divided into the no-interaction part H_F and the interaction H_I , owing to its translational invariance allows H_I to be written as

$$H_I = \int H_I(\vec{x})d\vec{x}. \tag{8}$$

Our consideration is focused upon various field models (local and nonlocal) in which the interaction density $H_I(\vec{x})$ consists of scalar $H_{sc}(\vec{x})$ and nonscalar $H_{nsc}(\vec{x})$ contributions:

$$H_I(\vec{x}) = H_{sc}(\vec{x}) + H_{nsc}(\vec{x}), \tag{9}$$

where the property to be a scalar means

$$U_F(\Lambda, b)H_{sc}(x)U_F^{-1}(\Lambda, b) = H_{sc}(\Lambda x + b), \quad \forall\ x = (t, \vec{x}) \tag{10}$$

for all Lorentz transformations Λ and spacetime shifts b.

As an illustration, in case of the vector mesons (ρ and ω) we have

$$V_{\text{v}} = V_{\text{v}}^{(1)} + V_{\text{v}}^{(2)},$$

$$V_{\text{v}}^{(1)} = \int d\vec{x}H_{sc}(\vec{x}),\ V_{\text{v}}^{(2)} = \int d\vec{x}H_{nsc}(\vec{x}),$$

$$H_{sc}(\vec{x}) = g_{\text{v}}\bar{\psi}(\vec{x})\gamma_\mu\psi(\vec{x})\varphi_{\text{v}}^\mu(\vec{x}) + \frac{f_{\text{v}}}{4m}\bar{\psi}(\vec{x})\sigma_{\mu\nu}\psi(\vec{x})\varphi_{\text{v}}^{\mu\nu}(\vec{x}),$$

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$$H_{nonsc}(\vec{x}) = \frac{g_{\rm v}^2}{2m_{\rm v}^2}\bar{\psi}(\vec{x})\gamma_0\psi(\vec{x})\bar{\psi}(\vec{x})\gamma_0\psi(\vec{x}) + \frac{f_{\rm v}^2}{4m^2}\bar{\psi}(\vec{x})\sigma_{0i}\psi(\vec{x})\bar{\psi}(\vec{x})\sigma_{0i}\psi(\vec{x}),$$

where $\varphi_{\rm v}^{\mu\nu}(\vec{x}) = \partial^\mu\varphi_{\rm v}^\nu(\vec{x}) - \partial^\nu\varphi_{\rm v}^\mu(\vec{x})$ is a tensor of a vector field in Schrödinger (S) picture. Such a situation is typical of theories with derivative couplings or spins $j \geq 1$.

2. BOOST GENERATORS. RELATIVISTIC INVARIANCE (RI) AS A WHOLE

To free ourselves from any dependence on pre-existing field theories, the three boost operators $\vec{N} = (N^1, N^2, N^3)$ can be written as:

$$\vec{N} = \sum_{C=0}^{\infty}\sum_{A=0}^{\infty}\vec{N}_{CA}, \tag{11}$$

$$\vec{N}_{CA} = \sum\!\!\!\!\!\!\int \vec{N}_{CA}(1', 2', ..., n'_C; 1, 2, ..., n_A) \times a^\dagger(1')a^\dagger(2')...a^\dagger(n'_C)a(n_A)...a(2)a(1). \tag{12}$$

We have developed an algebraic procedure to find links between coefficients H_{CA} and $\vec{N}_{CA}$, compatible with commutations

$$[P_i, P_j] = 0, \quad [J_i, J_j] = i\varepsilon_{ijk}J_k, \quad [J_i, P_j] = i\varepsilon_{ijk}P_k,$$
$$[\vec{P}, H] = 0, \quad [\vec{J}, H] = 0, \quad [J_i, N_j] = i\varepsilon_{ijk}N_k,$$
$$[P_i, N_j] = i\delta_{ij}H, \quad [H, \vec{N}] = i\vec{P}, \quad [N_i, N_j] = -i\varepsilon_{ijk}J_k,$$
$$(i, j, k = 1, 2, 3),$$

where $\vec{P} = (P^1, P^2, P^3)$ and $\vec{J} = (J^1, J^2, J^3)$ are linear and angular momentum operators.

For instant form of the relativistic dynamics after Dirac only Hamiltonian and boost operators carry interactions, viz.,

$$H = H_F + H_I, \quad \vec{N} = \vec{N}_F + \vec{N}_I,$$

while $\vec{P} = \vec{P}_F$ and $\vec{J} = \vec{J}_F$.

How one can build up operators H_I and $\vec{N}_I$ is shown in [4]. Here we would like to present only a free part of the fermion boost operator

$$\vec{N}_{ferm} = \vec{N}_{ferm}^{orb} + \vec{N}_{ferm}^{spin},$$

where

$$\vec{N}_{ferm}^{orb} = \frac{i}{2}\sum\!\!\!\!\!\!\int d\vec{p}\,E_{\vec{p}}\left(\frac{\partial b^\dagger(\vec{p}\mu)}{\partial\vec{p}}b(\vec{p}\mu) - b^\dagger(\vec{p}\mu)\frac{\partial b(\vec{p}\mu)}{\partial\vec{p}}\frac{\partial d^\dagger(\vec{p}\mu)}{\partial\vec{p}}d(\vec{p}\mu) - d^\dagger(\vec{p}\mu)\frac{\partial d(\vec{p}\mu)}{\partial\vec{p}}\right),$$

$$\vec{N}_{ferm}^{spin} = -\frac{1}{2}\sum\!\!\!\!\!\!\int d\vec{p}\,\vec{p}\times\frac{\chi^\dagger(\mu)\vec{\sigma}\chi(\mu)}{E_{\vec{p}} + m} \times \left(b^\dagger(\vec{p}\mu)b(\vec{p}\mu) + d^\dagger(\vec{p}\mu)d(\vec{p}\mu)\right).$$

Here $E_{\vec{p}} = \sqrt{\vec{p}^2 + m^2}$ is the nucleon energy and $\chi(\mu)$ is the Pauli spinor.

3. METHOD OF UCTs IN ACTION

Method in question is aimed at expressing a field Hamiltonian through the so-called clothed-particle creation (annihilation) operators α_c, e.g., $a_c^\dagger(a_c)$, $b_c^\dagger(b_c)$ and $d_c^\dagger(d_c)$ via UCTs $W(\alpha_c) = W(\alpha) = \exp R,\ R = -R^\dagger$ in similarity transformation

$$\alpha = W(\alpha_c)\alpha_c W^\dagger(\alpha_c) \tag{13}$$

that connect primary set α in bare-particle representation (BPR) with the new operators in CPR.

A key point of the clothing procedure is to remove the so-called bad terms from Hamiltonian

$$H \equiv H(\alpha) = H_F(\alpha) + H_I(\alpha) = W(\alpha_c)H(\alpha_c)W^\dagger(\alpha_c) \equiv K(\alpha_c). \tag{14}$$

By definition, such terms prevent physical vacuum $|\Omega\rangle$ (H lowest eigenstate) and one-clothed-particle states $|n\rangle_c = a_c^\dagger(n)|\Omega\rangle$ to be H eigenvectors for all n included. Bad terms occur every time when any normally ordered product

$$a^\dagger(1')a^\dagger(2')...a^\dagger(n'_C)a(n_A)...a(2)a(1)$$

of class [C.A] embodies, at least, one substructure $\in$ $[k.0]$ ($k = 1, 2...$) or/and $[k.1]$ ($k = 2, 3, ...$). In this context all primary Yukawa-type (trilinear) couplings shown above should be eliminated.

Respectively, let us write for boson–fermion system

$$H_I(\alpha) = V(\alpha) + V_{ren}(\alpha) \tag{15}$$

with primary (trial) interaction $V(\alpha) = V_{bad} + V_{good}$ "good" (e.g., $\in [k.2]$) as antithesis of "bad" while $V_{ren}(\alpha) \sim [1.1] + [0.2] + [2.0]$ "mass renormalization counterterms". It turns out that latter are important to ensure RI as a whole, i.e., in Dirac sense.

In order to compare our calculations with those by Bonn group [5] we have employed $V(\alpha) = V_{\rm s} + V_{\rm ps} + V_{\rm v}$. Then clothing itself is prompted by

$$H(\alpha) = K(\alpha_c) \equiv W(\alpha_c)[H_F(\alpha_c) + V_{\rm v}(\alpha_c) + V_{ren}(\alpha_c)]W^\dagger(\alpha_c) \tag{16}$$

or

$$K(\alpha_c) = H_F(\alpha_c) + V_{\rm v}^{(1)}(\alpha_c) + [R, H_F] + V_{\rm v}^{(2)}(\alpha_c) + [R, V_{\rm v}^{(1)}] + \frac{1}{2}[R,[R,H_F]] + [R, V_{\rm v}^{(2)}] + \frac{1}{2}[R,[R,V_{\rm v}^{(1)}] + ... \tag{17}$$

and requiring $[R, H_F] = -V_{\rm v}^{(1)}$ for the operator R of interest to get

$$H = K(\alpha_c) = K_F + K_I \tag{18}$$

with a new free part $K_F = H_F(\alpha_c) \sim a_c^\dagger a_c$ and interaction

$$K_I = \frac{1}{2}[R, V_{\rm v}^{(1)}] + V_{\rm v}^{(2)} + \frac{1}{3}[R,[R,V_{\rm v}^{(1)}]] + ... \quad (19)$$

between clothed particles.

Moreover, after modest effort we have

$$\frac{1}{2}\left[R, V_{\rm v}^{(1)}\right](NN \to NN)$$
$$= K_{\rm v}(NN \to NN) + K_{cont}(NN \to NN), \quad (20)$$

where the operator $K_{cont}(NN \to NN)$ may be associated with a contact interaction since it does not contain any propagators (details see in Refs. [3]). It has turned out that this operator cancels completely non-scalar operator $V^{(2)}$.

In parallel, we have

$$\vec{N}(\alpha) = \vec{B}(\alpha_c)$$
$$= W(\alpha_c)\{\vec{N}_F(\alpha) + \vec{N}_I(\alpha) + \vec{N}_{ren}(\alpha)\}W^\dagger(\alpha_c) \quad (21)$$

with

$$\vec{N}_I = -\int \vec{x}V_{\rm v}(\vec{x})d\vec{x} =$$
$$-\int \vec{x}\{V_{\rm v}^{(1)}(\vec{x}) + V_{\rm v}^{(2)}(\vec{x})\}d\vec{x} = \vec{N}_I^{(1)} + \vec{N}_I^{(2)}. \quad (22)$$

As before (see Refs. [2,3]) we find that the boost generator in CPR acquires the structure similar to $K(\alpha_c)$:

$$\vec{B}(\alpha_c) = \vec{B}_F + \vec{B}_I. \quad (23)$$

Here $\vec{B}_F = \vec{N}_F(\alpha_c)$ boost operator for noninteracting clothed particles (in our case fermions and vector mesons) and $\vec{B}_I$ incorporates contributions induced by interactions between them

$$\vec{B}_I = +\frac{1}{2}[R, \vec{N}_I^{(1)}] + \frac{1}{3}[R,[R,\vec{N}_I^{(1)}]] + ...$$

4. RELATIVISTIC INTERACTIONS

Operator K_I contains only interactions responsible for physical processes, these quasipotentials between the clothed particles, e.g.,

$$K_I \sim a_c^\dagger b_c^\dagger a_c b_c(\pi N \to \pi N) + b_c^\dagger b_c^\dagger b_c b_c(NN \to NN)$$
$$+ d_c^\dagger d_c^\dagger d_c d_c(\bar{N}\bar{N} \to \bar{N}\bar{N}) + ...$$
$$+ [a_c^\dagger a_c^\dagger b_c d_c + H.c.](N\bar{N} \leftrightarrow 2\pi) + ...$$
$$+ [a_c^\dagger b_c^\dagger b_c^\dagger b_c b_c + H.c.](NN \leftrightarrow \pi NN) + ... \quad (24)$$

After normal ordering of fermion operators we derive $NN \to NN$ interaction operator (mediated, for instance, by pions)

$$K_{NN} = \int d\vec{p}_1 d\vec{p}_2 d\vec{p}_1' d\vec{p}_2' V_{NN}(\vec{p}_1', \vec{p}_2'; \vec{p}_1, \vec{p}_2)$$
$$\times b_c^\dagger(\vec{p}_1') b_c^\dagger(\vec{p}_2') b_c(\vec{p}_1) b_c(\vec{p}_2), \quad (25)$$

$$V_{NN}(\vec{p}_1', \vec{p}_2'; \vec{p}_1, \vec{p}_2) = -\frac{1}{2}\frac{g^2}{(2\pi)^3}\frac{m^2}{\sqrt{E_{\vec{p}_1}E_{\vec{p}_2}E_{\vec{p}_1'}E_{\vec{p}_2'}}}$$
$$\times \delta(\vec{p}_1' + \vec{p}_2' - \vec{p}_1 - \vec{p}_2)$$
$$\times \bar{u}(\vec{p}_1')\gamma_5 u(\vec{p}_1)\frac{1}{(p_1 - p_1')^2 - \mu^2}\bar{u}(\vec{p}_2')\gamma_5 u(\vec{p}_2). \quad (26)$$

The corresponding relativistic and properly symmetrized NN quasipotential is

$$\tilde{V}_{NN}(\vec{p}_1', \vec{p}_2'; \vec{p}_1, \vec{p}_2)$$
$$= \left\langle b_c^\dagger(\vec{p}_1') b_c^\dagger(\vec{p}_2')\Omega \mid K_{NN} \mid b_c^\dagger(\vec{p}_1) b_c^\dagger(\vec{p}_2)\Omega\right\rangle, \quad (27)$$

or through covariant (Feynman-like) "propagators":

$$\tilde{V}_{NN}(\vec{p}_1', \vec{p}_2'; \vec{p}_1, \vec{p}_2) = -\frac{1}{2}\frac{g^2}{(2\pi)^3}\frac{m^2}{2\sqrt{E_{\vec{p}_1}E_{\vec{p}_2}E_{\vec{p}_1'}E_{\vec{p}_2'}}}$$
$$\times \delta(\vec{p}_1' + \vec{p}_2' - \vec{p}_1 - \vec{p}_2)$$
$$\times \bar{u}(\vec{p}_1')\gamma_5 u(\vec{p}_1)\frac{1}{2}\left\{\frac{1}{(p_1 - p_1')^2 - \mu^2}\right.$$
$$\left.+\frac{1}{(p_2 - p_2')^2 - \mu^2}\right\}\bar{u}(\vec{p}_2')\gamma_5 u(\vec{p}_2) - (1 \leftrightarrow 2). \quad (28)$$

Distinctive feature of potential (28) is the presence of covariant (Feynman-like) "propagator":

$$\frac{1}{2}\left\{\frac{1}{(p_1 - p_1')^2 - \mu^2} + \frac{1}{(p_2 - p_2')^2 - \mu^2}\right\}.$$

On the energy shell for NN scattering, that is

$$E_i \equiv E_{\vec{p}_1} + E_{\vec{p}_2} = E_{\vec{p}_1'} + E_{\vec{p}_2'} \equiv E_f,$$

this expression is converted into the genuine Feynman propagator.

These quasipotentials form the kernel of the integral equation for the nucleon-nucleon scattering R-matrix:

$$\langle 1'2'|\,\bar{R}(E)\,|12\rangle = \langle 1'2'|\,\bar{K}_{NN}\,|12\rangle$$
$$+\sum\!\!\!\!\!\!\int_{34} \langle 1'2'|\,\bar{K}_{NN}\,|34\rangle\,\frac{\langle 34|\,\bar{R}(E)\,|12\rangle}{E - E_3 - E_4} \quad (29)$$

with $\bar{R}(E) = R(E)/2$ ($\bar{K}_{NN} = K_{NN}/2$), symbol $\sum\!\!\!\!\!\!\int_{34}$ implies the $p.v.$ integration.

5. DEUTERON PROPERTIES

The deuteron state $|\Psi_d(\vec{P})\rangle \in \mathcal{H}_{2N}$ in the CPR satisfies the eigenvalue equation

$$[K_F(\alpha_c) + K_I(\alpha_c)]|\Psi_d(\vec{P})\rangle = E_d|\Psi_d(\vec{P})\rangle \quad (30)$$

with $E_d = \sqrt{m_d^2 + \vec{P}^2}$, where $\vec{P}$ is the total deuteron momentum, $m_d = m_p + m_n - \varepsilon_d$ is the deuteron mass and ε_d represents the binding energy of the deuteron.

Using the approximation with $K_I(\alpha_c) = K(NN \to NN) = K_{NN}$ we arrive to a simpler eigenvalue problem

$$\left[K_F^N + K_{NN}\right]|\vec{P};M\rangle = E_d|\vec{P};M\rangle \quad (31)$$

in the subspace $\mathcal{H}_{2N}$ spanned onto the basis $b_c^\dagger b_c^\dagger|\Omega\rangle$ with $K_{NN} \sim b_c^\dagger b_c^\dagger b_c b_c$. Here M denotes the deuteron spin projection on the quantization axis.

The solution of this equation can be represented as

$$|\vec{P};M\rangle = \int d\vec{p}_1 d\vec{p}_2 D_M(\vec{P};\vec{p}_1\mu_1,\vec{p}_2\mu_2) \times b_c^\dagger(\vec{p}_1\mu_1)b_c^\dagger(\vec{p}_2\mu_2)|\Omega\rangle \quad (32)$$

with the coefficients $D_M(\vec{P};\vec{p}_1\mu_1,\vec{p}_2\mu_2) = \delta(\vec{P} - \vec{p}_1 - \vec{p}_2)\psi_M(\vec{p}_1\mu_1,\vec{p}_2\mu_2)$ that have the property $\psi_M(1,2) = -\psi_M(2,1)$.

In the deuteron rest frame the equation (31) takes the form

$$|\psi_M\rangle = \left[m_d - K_F^N\right]^{-1} K_{NN}|\psi_M\rangle, \quad (33)$$

where

$$|\psi_M\rangle \equiv |\vec{P}=0;M\rangle = \int d\vec{p}\psi_M(\vec{p}\mu_1,-\vec{p}\mu_2)b_c^\dagger(\vec{p}\mu_1)b_c^\dagger(-\vec{p}\mu_2)|\Omega\rangle. \quad (34)$$

Using the basis vectors $|p(lS)JM_J,TM_T\rangle$ introduced in our previous paper [3] (see Appendix B) the vector $|\psi_M\rangle$ can be written as

$$|\psi_{M,TM_T}\rangle = \frac{1}{\sqrt{2}}\sum\int p^2dp\,|p(lS)1M,TM_T\rangle\psi_{lST}(p), \quad (35)$$

since the deuteron has the invariant spin equal $J=1$. In Eq. (35) the permissible values of the quantum numbers l, S and T are restricted to the property

$$\mathcal{P}_{ferm}|\psi_{M,TM_T}\rangle = |\psi_{M,TM_T}\rangle \quad (36)$$

with respect to the space inversion (see Appendix B in [1], where one can find formula (114) for the parity operator $\mathcal{P}_{ferm}$ of the nucleon field in the CPR). In fact, there are only the two combinations of T, S and l, namely, $T=0$, $S=1$ and $l=0,2$. Respectively,

$$|\psi_{M,00}\rangle \equiv |\psi_M\rangle = \frac{1}{\sqrt{2}}\sum_{l=0,2}\int p^2dp\,|p(l1)1M\rangle\psi_l(p). \quad (37)$$

At this point, we accept the normalization condition

$$\langle\psi_{M'}|\psi_M\rangle = \delta_{M'M} \quad (38)$$

that implies

$$\int_0^\infty p^2dp\left[\psi_0^2(p)+\psi_2^2(p)\right] = 1. \quad (39)$$

Substituting the decomposition (37) into the equation (33) we get the set of homogeneous integral equations for "radial" components $\psi_l(p)$ $(l=0,2)$:

$$\psi_l(p) = \frac{1}{m_d - 2E_{\vec{p}}} \times \sum_{l'}\int k^2dkV_{l\,l'}^{J=S=1,T=0}(p,k)\psi_{l'}(k). \quad (40)$$

In a moving frame the corresponding eigenvector that belongs to the value $E_d = \sqrt{\vec{P}^2 + m_d^2}$ can be determined either by solving directly the equation (31) or using the relation

$$|\vec{P};M\rangle = \exp[i\vec{\beta}\vec{B}(\alpha_c)]|\psi_M\rangle. \quad (41)$$

The boost operator $\vec{B}(\alpha_c) = \vec{B}_F(\alpha_c) + \vec{B}_I(\alpha_c)$, determined in the CPR by

$$\vec{B}(\alpha_c) = W(\alpha_c)\vec{N}(\alpha_c)W^\dagger(\alpha_c), \quad (42)$$

consists of the free $\vec{B}_F$ and interaction $\vec{B}_I$ parts. Here $\vec{N}$ is the total boost operator for interacting fields. Perhaps, one should note that the required

$$\hat{P}^\mu|\vec{P};M\rangle = P^\mu|\vec{P};M\rangle \quad (43)$$

follows from the property of the energy-momentum operator $\hat{P}^\mu = (H,\hat{P}^1,\hat{P}^2,\hat{P}^3)$ to be the four-vector.

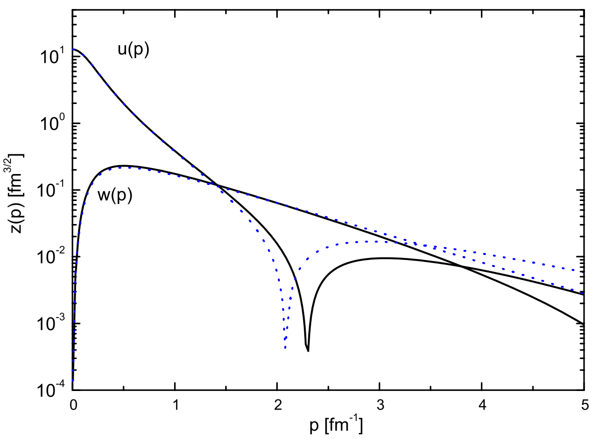
The parameters $(\beta^1,\beta^2,\beta^3) = \vec{\beta}$ for the Lorentz transformation $m_d(1,0,0,0) \Rightarrow (P^0,P^1,P^2,P^3) = P$ are related to the "velocity" $\vec{v} = \vec{P}/P^0$ of the moving frame as

$$\vec{\beta} = \beta\vec{n}, \quad \vec{n} = \vec{v}/v, \quad \tanh\beta = v. \quad (44)$$

As in our previous paper [3] we continue comparison of UCT approach with results of the Bonn group [5]. In particular, the low-energy parameters of NN scattering and deuteron properties are presented in Table 1 and the figure.The best-fit parameters are collected in Table 2.

Table 1. *Deuteron and low-energy parameters. The experimental values are from Table 4.2 of Ref. [5]*

Parameter	Bonn B	UCT	Experiment
a_s (fm)	−23.71	−23.57	−23.748±0.010
r_s (fm)	2.71	2.65	2.75±0.05
a_t (fm)	5.426	5.44	5.419±0.007
r_t (fm)	1.761	1.79	1.754±0.008
ε_d (MeV)	2.223	2.224	2.224575
P_D (%)	4.99	4.89	



Deuteron wave function components $\psi_0^d(p) = u(p)$ and $\psi_2^d(p) = w(p)$. Solid (dotted) curves calculated for the Bonn B (UCT) potential

Table 2. *The best-fit parameters for the two models. The row Potential B (UCT) taken from Table A.1 in [5] (obtained by least squares fitting to OBEP values in Table 1 of Ref. [3] including deuteron binding energy and low-energy parameters). All masses are in MeV, and $n_b = 1$ except for $n_\rho = n_\omega = 2$*

Model	Meson	π	η	ρ	ω	δ	σ, $T = 0$ ($T = 1$)
Potential B	$g^2/4\pi\,[f/g]$	14.4	3	0.9 [6.1]	24.5	2.488	18.3773 (8.9437)
	Λ	1700	1500	1850	1850	2000	2000 (1900)
	m	138.03	548.8	769	782.6	938	720 (550)
UCT	$g^2/4\pi\,[f/g]$	13.395	5.0	1.2 [6.1]	17.349	5.0	22.015 (5.514)
	Λ	2500	1219	1593	2494	2169	1200 (2500)
	m	138.03	548.8	769	782.6	938	720 (550)

6. CONCLUSIONS

Starting from a total Hamiltonian for interacting meson and nucleon fields, we come to the Hamiltonian and boost generator in the CPR whose interaction parts consist of new relativistic interactions responsible for physical (not virtual) processes, particularly, in the system of bosons ($\pi-$, $\eta-$, $\rho-$, $\omega-$, $\delta-$ and $\sigma-$mesons) and fermions (nucleons and antinucleons).

Using the unitary equivalence of CPR to BPR, we have seen how the NN scattering problem in QFT can be reduced to the three-dimensional LS-type equation for the T-matrix in momentum space. The equation kernel is given by clothed two-nucleon interaction of class [2.2].

Special attention has been paid to the elimination of auxiliary field components. We encounter such a necessity for interacting vector and fermion fields when in accordance with the canonical formalism the interaction Hamiltonian density embodies not only a scalar contribution but nonscalar terms too.

Being concerned with constructing two-nucleon states and their angular-momentum decomposition we have not used the so-called separable ansatz. The clothed two-nucleon partial waves have been built up as common eigenstates of the field total angular-momentum generator and its polarization (fermionic) part.

As a whole, persistent clouds of virtual particles are no longer explicitly contained in CPR, and their influence is included in properties of clothed particles (these quasiparticles of the UCT method). In addition, we would like to stress that problem of the mass and vertex renormalizations is intimately interwoven with constructing the interactions between clothed nucleons.

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РЕЛЯТИВИСТСКИЕ ВЗАИМОДЕЙСТВИЯ В МЕЗОН-НУКЛОННЫХ СИСТЕМАХ: ПРИМЕНЕНИЕ В ТЕОРИИ ЯДЕРНЫХ РЕАКЦИЙ

А.В. Шебеко, П.А. Фролов, Е.А. Дубовик

Показано, что метод унитарных одевающих преобразований (УОП), развитый в работах [1,2] и применённый к задачам ядерной физики [3,4], позволяет по-новому взглянуть на построение взаимодействий между “одетыми” нуклонами, этими квазичастицами со свойствами физических нуклонов.

РЕЛЯТИВІСТСЬКІ ВЗАЄМОДІЇ В МЕЗОН-НУКЛОННИХ СИСТЕМАХ: ЗАСТОСУВАННЯ В ТЕОРІЇ ЯДЕРНИХ РЕАКЦІЙ

О.В. Шебеко, П.О. Фролов, Є.О. Дубовик

Показано, що метод унітарних одягаючих перетворень (УОП), розроблений в працях [1,2] та застосований до задач ядерної фізики [3,4], дозволяє по-новому поглянути на побудову взаємодії між “одягненими” нуклонами, цими квазічастинками з властивостями фізичних нуклонів.