Bulgarian Journal of Physics 27 No 2 (2000) 16–19

30 YEARS NUCLEODYNAMICS

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30 years ago the author introduced a new basic nuclear law, eliminating faults of Yukawa's potential. Soon, using vector nuclear potential and Dirac-Pauli's equation, a relativistic theory was developed. Around 100 experimental data corroborate the theory. They include the deuteron binding energy, Pb energy levels, nucleon-nucleon and hyperon-nucleon scattering data. The developed quantum nucleodynamics confirms the results, and explains the proton superkern.

The nuclear interactions have not an official successful theory. The Yukawa potential contradicts Bouilleaud [1] and Newton that the density of an isotropic impulse flaw follows the inverse-square law. It cannot connect the binding energies of light and heavy nuclei [2]. QCD has some semiquantitative and qualitative successes, but is insufficient at large distances [3].

30 years ago [4] the author considered the advances of exponentially decreasing Newtonian (Laplacean) force [5], eliminating simply the part of Yukawa's force decreasing inversely proportionally to the distance. A complementary argumentation was found later [6-11]. The obtained force is

$$F = -\frac{g_1 g_2}{4\pi r^2}\exp(-\mu r), \tag{1}$$

where r is the distance between the interacting nuclear point-like charges g_1 and g_2 ; μ is the Yukawa constant

$$\mu = m_\pi c / \hbar , \tag{2}$$

where m_π is the rest mass of the neutral pion, c is the speed of light in vacuum, and $\hbar$ is the Dirac action constant.

The constant of nuclear interaction is [12, 9]

$$\alpha_g = g^2 / 4\pi \hbar c = 1/4 , \tag{3}$$

i.e. the nucleon nuclear charge is

$$g = (\pi \hbar c)^{1/2} . \tag{4}$$

The nuclear potentials at rest are

$$U_0 = -gE_2(\mu r)/4\pi r, \tag{5}$$

$$\mathbf{A}_0 = \exp(-\mu r)(\mathbf{r}\times\boldsymbol{\mu}_0)/4\pi c r^3 , \tag{6}$$

where $E_2(\mu r)$ is an exponential integral [13], $\mathbf{r}$ is the position vector of the field point with respect to the source, and

$$\boldsymbol{\mu}_0 = (1+\alpha_g/2\pi - 16) g\hbar\boldsymbol{\sigma}/2m_p \tag{7}$$

is the nuclear analog of the magnetic moment (nucleodynamic moment) at rest with accuracy to the first radiation correction. m_p is the proton mass at rest, and $\boldsymbol{\sigma}$ - the Pauli matrix.

It merits a special attention that the theory uses only 3 theoretical constants (μ, α_g, $\boldsymbol{\mu}_0$), where the integers 4 (α_g) and 16 appear, the latter being a supplementary Dirac's contribution to the nucleodynamic moment. This adds an obvious advance of the theory.

This potentials participate in the accommodated for the nuclear interactions Dirac-Pauli equation (the nuclear Dirac equation). The application to the deuteron binding energy [12] corroborated it.

A following key success was the spectrum of neutron energy levels of Pb^{209} [14, 15].

Finally, cross-sections of $np, pp, nn, \Lambda p$ and $\Sigma^+ p$ scattering were calculated (initially in Hermitean approximation [16]). The following refinements [17, 18] confirmed the agreement with the experiments. My last reviews are [19, 18].

The number of the checked experimental data overcomes 100. We find full correspondence with basic experimental facts in the nuclear region. The list of the obtained results and effects overcomes 60 cases [20].

It includes the nuclear analogs of the magnetic force [7, 21], Biot-Savart's law [21], the Lorentz force [21], and the electromagnetic induction [22]; the nucleodynamic moment [22], the potential impulse and its moment [22], quantum nucleodynamics [8], first (Schwinger's) radiation correction to the nucleodynamic moment [12], nucleodynamic waves and retarded potentials [22]; spin-spin, spin-orbital and tensor nuclear interactions [12, 22]; the spin-spin force is the dominant nuclear force [22]; velocity, energy, and state dependence of the effective (equivalent) Schroedinger potential [12, 22]; non-linear effects [12, 23], the saturation of the nuclear forces [7, 15], peculiarities of the nuclear potential wells [12], nucleon distribution in nuclei [14, 15], nuclear energy levels [14, 15], new members of the equivalent Schroedinger potential [12, 17], the origin and position of the hard potential core [12], the deuteron binding energy [12], the helium-4 binding energy [7], nucleon-nucleon and hyperon-nucleon elastic scattering cross-sections [16, 17, 19], the hard core as a limit of the elastic cross-sections [17], the confinement [18], nucleon trajectories in Laplacean field (laplasoids) [24], spin flip [16], the Yukawa potential is an asymptote of the Laplacean potential [7], the proton superkern [25], perspectives of the nuclear energetics, and others. New fundamental results wait for publication.

Thus we find a full correspondence to basic nuclear facts. The theory is logically completed and has not effective nuclear rivals.

Quantum nucleodynamics (QND) was developed in 1975 [8]. It appeared by natural generalization of the basic principles of quantum electrodynamics to nuclear interactions and the analogy between classical electrodynamics and nucleodynamics in result of their common relativistic origin [22].

In the case of our approximation (second order differential equation) QND demands a minimal correction. In the Hamiltonian [26] we must use the correction for the kinetic energy of the source in the form

$$\delta H_k = -(\hbar^2 k_1 / 2m_1)\Delta . \qquad (8)$$

Here m_1 is the rest mass of the field source. This modified correction makes the common factor before the Laplace operator Δ in the obtained differential equation proportional to the expression $k_1 = 1 + (V_{g\,0} + V_{e\,0}) / m_1 c^2$, where $V_{g\,0}$ and $V_{e\,0}$ are respectively the static nuclear and electric potential energies.

$k_1 = 0$ corresponds to a point which we could call "nuclear analog of the electromagnetic radius of a particle". Then the wave function vanishes too, and the equivalent triplet Schroedinger potential is infinitely high. This is the experimentally discovered proton superkern ($r_p = 0.0447$ *fm* for pp interaction). Let us remember that the vanishing of the wave function at $k_1 = 0$ appeared automatically in the Hermitean approximation, used in Ref. [23]. Then, with np interaction, I obtained the point $x_0 = \mu r_0 = 0.031542678$. In the case of pp interaction the corresponding point is $x'_0 = 0.305929168$.This is a new crucial corroboration of the Laplacean force (1) in nuclear physics.

Some results are presented in Table I. The data enclose the interval of energies in which nuclei could exist, since 42 MeV is the depth of the nuclear potential well of the heavy nuclei. The upper binding energy is essentially less. Under 10 MeV the cross sections go out of the region of real action of the nuclear forces, and the data are explained only by the electromagnetic theory.

Table I. np scattering

E_{lab}, MeV	η_0, rad	η_1, rad	σ_0, mb	σ_e, mb	$\sigma_0 - \sigma_e$, mb
10.42	1.1327	1.7598	929.5	940±20	-10.5
11.13	1.1205	1.7321	874.6	880±20	- 5.4
12.80	1.0939	1.6733	765.5	830±90	-64.5
13.13	1.0890	1.6625	746.7	760±20	-13.3
14.00	1.0763	1.6353	700.7	700±60	0.7
14.10	1.0749	1.6323	695.8	689±5	6.8
14.20	1.0735	1.6293	690.8	675±20	15.8
15	1.0625	1.6060	653.5	660±70	- 6.5
16.13	1.0477	1.5750	606.3	634±34	-27.7
16.46	1.0436	1.5664	593.6	580±33	13.6
17.15	1.0350	1.5489	568.3	561±29	7.3
17.90	1.0261	1.5306	542.9	533±27	9.9
18.29	1.0215	1.5213	530.4	517±27	13.4
18.69	1.0169	1.5121	518.0	523±28	- 5
19.11	1.0122	1.5025	505.6	498±40	7.6
19.66	1.0061	1.4904	490.0	494.2±2.5	- 4.2
20.00	1.0024	1.4830	480.7	479±24	1.7
20.93	0.9925	1.4635	456.8	449±21	7.8
21.41	0.9876	1.4537	445.2	447±20	- 1.8
21.91	0.9825	1.4438	433.7	420±20	13.7
22.43	0.9773	1.4336	422.1	408±20	14.1
23.51	0.9669	1.4134	399.7	397.7±16	2.0
24.09	0.9614	1.4028	388.4	393.0±15	- 4.6
25.00	0.9531	1.3868	371.7	390±30	- 18
25.31	0.9503	1.3815	366.3	362.9±13.5	3.4
26.60	0.9390	1.3600	345.0	345.7±12.3	- 0.7
27.29	0.9331	1.3489	334.4	335.4±11.5	- 1.0
28.03	0.9270	1.3373	323.6	321.5±11.0	2.1
28.80	0.9207	1.3255	313.0	312.2±10.5	0.8
29.59	0.9144	1.3138	302.6	309.1±9.5	- 6.5
30.40	0.9081	1.3020	292.5	281.7±8.8	10.8
31.24	0.9017	1.2901	282.6	286.4±8.3	- 3.8
34.03	0.8815	1.2529	253.0	260.1±7.2	- 7.1
35.08	0.8742	1.2396	243.1	245.8±6.7	- 2.7
36.20	0.8667	1.2258	233.2	220.0±9.9	13.2
37.32	0.8593	1.2125	223.9	226.8±6.3	- 2.9
38	0.8550	1.2046	218.5	223±7.6	- 4.5
41.10±1.38	0.8358	1.1701	196.3	204.6±5.4±9	- 8.3
42.53±1.45	0.8275	1.1551	187.2	196.0±5.2±9	- 8.8

Legend: E_{lab} - kinetic energy of the incident neutron in the laboratory system, η_0 - $^1S_0$ phase shift, η_1 - $^3S_1$ phase shift, σ_0 - S cross section of np scattering, σ_e experimental cross section [27].

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