Yu.V.Novozhilov: Life in Science

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Contents

1. Biographical moments

YURI VIKTOROVICH NOVOZHILOV

Personal sheet for staff division (1982)

Born 13 November 1924 in Leningrad. Parents status: dvoryane, after the October revolution; sluzhashchie. Father Victor Valentinovich Novozhilov, scientist-economist, professor of the LPI, during the war - violinist of the the theatre of operette. Mother, Elena Robertovna Novozhilova, born Shleifer, law consultant, member of the advocate collegium. During the war - secretary at the theatre of operette.

1941-1943 -student of the Kazan aviational institute. September 1943- october 1943 - student of the Voronezh aviational institute at Tashkent. October 1943- 1948 student of LPI department of theoretical physics. Graduated as research engineer in techniclal physics. 1948-1949 engineer, then senior engineer at "Elektrosila" works. Simultaneously was teaching at the physical faculty of LGU. On the 01.10.1949 was nominated assistant professor of LGU from which date was working at LGU. Associated professor since 30.03 1953. Full professor since 1960.

Candidate of phys.-mat science 1952. Doctor of phys.-mat science 1958

1961 -1992 head of chair of nuclear and elementary particle physics. 1960- 1964 - vice-rector for scientific affairs, 1968 - 1972 - dean of the physical faculty,

1965-1966 -party secretary of the physical faculty,

1973- 1981 director of scientific policy and information of UNESCO, later vice-director of the science sector of UNESCO.

From 1986 head of theoretical division of the Fock institute of theoretical physics.

He was vice-president of the Physical Society of USSR, vice-president of the Euroasian Physical Society, member of the Unesco counsel on physics, member of the International association of mathematical physics, full member of the Academy for natural sciences (RAEN)
Yu.V.Novoshilov published about 200 papers, monography "Introduction to the theory of elementary particles" (1972) published also in England, textbook "Electrodynamics" (with Yu.A.Yappa, 1978) twice published in English, and a popular book "Elementary particles" (1963) translated into English, German, Polish, Rumenian, Chech and Chinese.
Here we can only briefly discuss his main scientific contributions.

2. The start: Fock's functionals

Scientific life of Yu.V. started under the influence of two outstanding physicists of that time: member-corr. of academy Ya.I.Frenkel and academician V.A.Fock. From these two great personalities, so different from each other, Y.V. inherited devotion to science, taste for investigations on the frontline, true understanding of actuality of the problems to be studied, rigorous mathematical approach combined with physical intuition.
The initial stage of scientific activity of Yu.V. coincided with the period of explosive growth of the quantum field theory and theory of elementary particles in 1940-1950 - development of the renormalization theory and relativistic scattering theory. Plenitude of new ideas and extrafast rythm of investigation characterisic for this period determined the direction and working style of Yu.V.

In this time Yu.V. published his papers on the metod of functionals in the Quantum Field Theory. There he developed the renormalization program in the functional framework, studied the problem of variation of functional in Fermi fields. The keen interest of Yu. V. to the method of functionals forsaw a distant future, when in the 1970-s this method became the main one for the analysis of gauge fields. The review of Yu.V. and A.V.Tulub "Metod of functionals in the quantum field theory", published as a separate book in the US, for a long time was the only material in this field and has not lost its actuality at present. In 1953 Yu.V. was awarded the first university prize for the paper "Application of Fock's functional method to the problem of self-energy".

This is the first paper of Yu.V. From the annotation:
"Method of Fock's functionals is used for the derivation of the Dirac equation with radiative corrections"
In the functional method a state is described by an analytic functional $\Omega\{\alpha(x)\}$ of the complex function $\alpha(x)$. Creation and elimination operators $a^\dagger(x)$ anf $a(x)$ correspond to multiplication by $\alpha(x)$ and functional derivative in it.
For the Dirac equation in QED the starting point is the equation for the state functional Ω

$$\left[\hat{\partial} + m_0 - ie_0(\hat{A} + \hat{B})\right]\Omega = 0$$

where A and B are the external and proper electromagnetic potentials, both in the Coulomb gauge, and m_0 and e_0 are the bare mass and electric charge of the electron. Here

$$\Omega = \sum_n \frac{1}{\sqrt{n!}} \int d\tau_n u_n(k_1, ...k_n) b(k_1) ... b) b(k_n)$$

and $d\tau_n$ is the phase volume of the n-photon atate, k_i are momenta and polarizations of the photons and $b(k)$ is a function reperesenting a photon in state k (the eigenvalue of the corresponding creation operator). The annihilation operators act as derivatives $\partial/\partial b(k)$. Restricting to zero- and one-photon states, the equation for the functional gives a pair of equations for functions u_0 and u_1

$$\left[\hat{\partial} + m_0 - ie_0\hat{A}\right] u_0 = ie < 0|\hat{B}|1 > u_1$$

$$\left[\hat{\partial} + m_0 - ie_0\hat{A}\right] u_1 = ie < 1|\hat{B}|1 > u_0$$

With the use of Green functions of the Dirac equation in the external field $K(x, x')$ and the photon propagator $D(x - x')$ one obtains an equation for u_0

$$\left[\hat{\partial} + m_0 - ie\hat{A}\right] u_0(x) = e^2 \int d^4x' D(x - x') K(x, x') u_0(x')$$

in which one clearly sees the electromagnetic mass of the electron including the radiative corrections in the lowest order.

Next the standard renormalization procedure is applied introducing the physical mass and charge m and e, which allows to eliminate the ultraviolet divergencies and obtain the standard expression for the radiative energy shift in the external Coulomb field of the atom.

3. Fock's functionals in Non-Abelian gauge theories.

After more than 30 years Yu.V. returned to the functional method in application to gauge theories. In his paper "Method of Fock's functionals and gauge invariance" (TMF, 1984) he built gauge invariant creation and elimination operators for quarks and gluons. Color group $SU(2)$ is considered in the axial or light-cone gauge. Gauge invariant (GI) state with N gluon creation operators is

$$\Phi_N \equiv \mathrm{Tr}\Big\{a^\dagger(p_1,x_1)U(x_1,x_2)a^\dagger(p_2,x_2)U(x_2,x_3)...a^\dagger(p_N,x_N)U(x_N,x_1)|0>$$

Here p is the longitudinal momentum and x variables related to the left gauge invariance under which

$$a^\dagger(p,x) \rightarrow S(x)a^\dagger(p,x)S^{-1}(x)$$

Standard phase factors are just Wilson lines

$$U(x_1,x_2) = P\exp\int_{x_1}^{x_2} g(Adx)$$

The aim is to present this expression as a product of GI creation operators.

To do this instead of Wilson lines in the state functional a factorized expression independent of gluon variables is introduced

$$U(x_1, x_2) \to v^{-1}(x_1)v(x_2)$$

where $v(x)$ is a $2 \otimes 2$ matrix which transforms as

$$v(x) \to S(x)v(x)$$

under the remaining gauge transformation. As a result the state functional takes the form

$$\Phi_N \mathrm{Tr}\Big\{\beta(p_1, x_1)\beta(p_2, x_2)...\beta(p_N, x_N)\Big\}|0>$$

where

$$\beta(p, x) = v^{-1}(x)\alpha(p, x)v(x)$$

Function β can be considered as a representative of the GI gluon creation operator.
Also the case when $v(x)$ can be taken differently in different gluon operators is considered. The problem of the vacuum state from the view of the newly introduced GI elimination operators is discussed.

4.Dressed particles

In the Quantum Field Theory interaction plays a double role. First it converts bare particles into real ones providing a cloud of virtual components. This part of the interaction does not vanish when particles are wide apart. Second part of the interaction is responsible for the physical interaction of these "dressed" particles. The method of dressed particles attempts to separate these two effects and take into account conversion of bare particle into real ones from the start.
A practical realization of this idea was made by Yu.V. in the framework of a simple model for strong interactions fashionable in the 50-ies. At that iime it was expected than nucleon interactions could be well described by emission and absorption of pions neglecting the antinucleons and pion self-interaction.

The Hamiltonian of this model is

$$H = H^{\pi} + \sum_{i=1}^{n} \left[H_i^N + U_i \right]$$

where H^{π} H_i^N are Hamiltonians of the free pions and nucleon i, and U_i - the interaction of the i-th nucleon with the pion field with creation (annihilation) operators $a^{\dagger}(q)(a(q))$:

$$U_i(r) = \int d^3q \Big(V_i(q) a(q) e^{iqr} + h.c \Big)$$

The wave function of non-interacting dressed nucleons is constructed as a product

$$\Phi(k_1, k_2, ..k_n) = F_1(k_1, a^{\dagger}) F_2(k_2, a^{\dagger}) ... F(k_n, a^{\dagger}) |0>$$

where $F_i(k_i, a^{\dagger})|0>$ is the wave function of the i-th real (dressed) nucleon with momentum and spin k_i satisfying the equation

$$\left[H^{\pi} + H_i^N + U_i \right] F_i(k_i, a^{\dagger}) |0> = E(k_i) F_i(k_i, a^{\dagger}) |0>$$

where $E(k, i) = \sqrt{M_N^2 + \mathbf{k}^2}$ and M_N is the nucleon mass.

Basic states with extra pions are obtained by application of their creation operators

$$\Phi_{m,n} \equiv \Phi(q_1, q_2, ...q_m|k_1, k_2, ..k_n) = a^\dagger(q_1)a^\dagger(q_2)...a^\dagger(q_m)\Phi(k_1, k_2, ..k_n)$$

States $\Phi_{m,n}$ are used as initial and final in the consruction of the S-matrix.

$$S_{BA} =< \Psi_B^{(-)}|\Psi_A^{(+)} >= \delta_{BA} - 2\pi i T_{BA}$$

where $\Psi_A^{(\pm)}$ are eigenfunctions of H with the appropriate boundary conditions

$$\Psi_A^{(\pm)} = \Phi_A - \frac{1}{H - E_A \pm i\epsilon}\Big[(H - E_A)\Phi_A]$$

in which Φ_A are assumed to be taken in the dressed nucleon basis. The scattering matrix

$$T_{BA} =< \Psi_B^{(-)}|H - E_A|\Phi_A >$$

staifies the equation

$$T_{BA} =< \Phi_B|H - E_A|\Phi_A > - \sum_C \frac{T^*_{CB}T_{CA}}{E_C - E_B - i\epsilon}$$

and so is fully determined by the inhomogeneous term in this equation.

For the calculation of the latter a technique is proposed to introduce separate pion variables for different nucleons. Independent creation and annihilation operators are introduced for the pion cloud of each nucleon $a_i^\dagger(q)$ and $a_i(q)$, so that each nucleon state is $F_i(k_i, a_i^\dagger)|0>$. New dressed states

$$\Phi^{(0)}(k_1, k_2, ..k_n) = F_1(k_1, a_1^\dagger)F_2(k_2, a_2^\dagger)...F(k_n, a_n^\dagger)|0>$$

are orthogonal and asymptotically coincide with Φ. Calculations give

$$< \Phi_B|H - E_A|\Phi_A >=< \Phi_B^{(0)}| : [1 + \hat{N}]L(a, a^\dagger) : |\Phi_A(0)>$$

$$1 + \hat{N} =: \exp \sum_{i \neq j} \int d^3q a_i^\dagger(q) a_j(q) :$$

Here $a(q) = \sum_i a_i(q)$, $a^\dagger = \sum_i a_i^\dagger(q)$ and $L(a^\dagger, a)$ is a certain operator determined from the form of the interaction. It is important that all effects of the nucleon self-mass are automatically taken into account by using the dressed particle basis.

This technique was used by Yu.V. in a series of papers written together with his pupils for construction of the two-nucleon potential in the model. These papers formed the basis of his doctoral thesis.

5. Poincare group

In the 60-s in view of discovery of numerous new hadrons a shft towards the investigation of symmetries of fundamental interactions was taking place. An that time the study of the current algebra showed that important simplifications occur with the use of infinite momentum system, related to the light-cone variables. This motivated Yu.V. together with E.V.Prokhvatilov to consider representations of the Poincare group in these variables (in $E(2)$ basis) "Representation of the Poincare group in $E(2)$ basis", (Yad. Fiz, 1969) The results of this paper conserve their importance for construction of the quantum field theory in light-cone variables up to the present.

The standard Poincare group is considered with generatots $M_{\mu\nu}$, P_μ. In the canonical basis $|\mathbf{p}, m, s, M>$ the diagonal operators are $\mathbf{P}$, the 3d spin projection m, spin s and mass M. In $E(2)$ basis the diagonal operators are chosen as $E_{(1,2)} = M_{0(1,2)} + M_{3(1,2)}$, $P_0 + P_3$, $K_3 = (W_0 + W_3)/(P_0 + P_3)$, (where $W_\mu = (1/2)\epsilon_{\mu\nu\rho\sigma} P^\nu M^{\rho\sigma}$), operators of spin and mass with eigenvalues ϵ_1, ϵ_2, μ, k, s M The eigenvectors accordingly are $|E(2) > \equiv |\epsilon_1\epsilon_2, \mu, k, s, M>$.

In the paper an explicit representation is found for the non-diagonal operators. Let

$$\eta = \frac{\partial}{\partial \epsilon}, \quad \xi = \mu \frac{\partial}{\partial \mu}$$

Then

$$< E(2)|P_{1,2}| = i\mu\eta_{1,2} < E(2)|$$

$$< E(2)|(P_0 - P_3) = \Big[-\eta_1^2 - \eta_2^2 + \frac{M^2}{\mu}\Big) < E(2)|$$

$$< E(2)|M_{12} = \Big(i\epsilon_2\eta_1 - i\epsilon_1\eta_2 + k \Big) < E(2)|$$

$$< E(2)|M_{03} = \frac{1}{i}\Big(1 + \epsilon_1\eta_1 + \epsilon_2\eta_2 + \xi\Big) < E(2)|$$

$$< E(2)|(M_{01} - M_{31}) = \Big(\epsilon_1\eta_1^2 - \epsilon_1\eta_2^2 + 2\epsilon_2\eta_1\eta_2$$

$$+2\eta_1 + 2\eta_1\xi + \eta M^2/\mu^2 - 2MK_2/\mu - 2ik\eta_2\Big) < E(2)|$$

$< E(2)|(M_{02} - M_{32})|$ is obtained from the previous expression by $1 \leftrightarrow 2$. Here $K_{(1,2)} = (W_{(1,2)} - K_3 P_{(1,2)})/M$ and its action is given by

$$< \epsilon_1, \epsilon_2, \mu, k, s, M|(K_1 \pm iK_2) =$$

$$\sqrt{(s \pm k)(s \mp k + 1)} < \epsilon_1, \epsilon_2, \mu, k \mp 1, s, M|$$

In the paper also the transition formulas from the $E(2)$ basis to the canonical one are derived.

So the paper gives a complete solution of the representation of the Poincare group in the $E(2)$ basis.

6. Bosonization

A series of papers by Yu.V. and co-authors, which gained a wide recognition, is releted to the idea of bosonization of fermions in the quantum field theory in the presence of anomalies. Its fundamentals are the following. Let fermions be in the external, say, axial field A. They are described by the functional integral

$$Z(A) = \int DqD\bar{q}e^{iS(q,A)}$$

where $S(q,A)$ is the standard action for the fermion in an external field. Make a local unitary transformation of the fermion field

$$q \to Uq.$$

Then

$$S(q,A) \to S(q,A^U), \quad Z(A) \to Z(A^U)$$

On the other hand transformation $q \to Uq$ can be considered as just a transition to new integtration variables $q \to q' = Uq$. If the integration measure is invariant under transformation U this will not change the integral. In this case $Z(A^U) = Z(A)$ and so does not depend on U, which disappears from the theory.

However in the presence of anomalies in the quantized theory the measure may become to be non-invariamt and $Z(A)$, which actually is the fermion determinant in the external field, turns out to be dependent on the field generating the anomaly. In this case $Z(A^U)$ depends on U.
This effect used to be expressed by introduction of the effective action $W(U, A)$ putting

$$Z_{inv}(A) = \frac{\int DUe^{iW(U,A)}}{\int DUZ^{-1}(A^U)}$$

where it is assumed that $Z_{inv}(A^U) = Z_{inv}(A)$ by definition. The validity of this particular normalization can be checked in absence of the invariance after division by $\int DU$, when $W(U, A) = 0$.
This formula is interpreted as bosonization; change of initial fermion variables on the lefthand side by bosonic ones U on the righthand side. The invariant denominator can be considered as depending on invariant fermionic variables $\{Uq, \bar{q}U$, so that the effective action desribes the non-invariant part of the fermion field.

Actually breaking of invariance by anomalies shows itself ony in the region of low energies. Beecause of that bosonization serves to construct effective low energy Lagrangians.
The method of bosonization can be realized in theories with different starting Lagrangians and sets of external fields. Among these applications papers of Yu.V. with co-authors occupy an outstanding place.
We briefly dscuss a pair of them which are most indicative of the contribution of Yu.V. to the application of bosonization in the low-energty region.

1) "Chiral bozonization in non-abelian gauge theories", (A.A.Andrianov and Yu.V.Novozhilov, Phys. Lett. B (1985)) The standard QCD is considered in the presence of an external axial vector field A. The quark functional Z_q is split in two factors $Z_q = Z_q^\Lambda \tilde{Z}_q$, where $\tilde{Z}_q$ is chiral invariant and non-invariance is concentrated in Z_q^Λ, where Λ restricts the low energy region. The chiral transformation of the quark field is introduced

$$q \to q^U = \frac{1}{2}[U(1-\gamma_5) + (1+\gamma_5)]q$$

The effective action is then derived taking into account the chiral anomaly on the lines explained earlier. For illustration we present a part of it containing the colour chiral field only

$$W_{eff}(U) = \int d^4x \mathrm{Tr}\Big\{ \frac{N_F \Lambda^2}{16\pi^2} \partial U \partial U^{-1} + \frac{N_F}{192\pi^2} (\partial U \partial U)(\partial U^{-1} \partial U^{-1})$$

$$- \frac{1}{32 g^2} [U\partial_\mu U^{-1}, U\partial_\nu U^{-1}]^2 \Big\} - N_f W_{WZW}$$

where W_{WZW} is the known Wess-Zumino-Witten action.
The authors note "While the chiral field in the flavour case describes physical objects, the colour chiral field is of the same reality as quarks and gluons. In the limit $\Lambda \to \infty$ chiral fields disappear leaving us with the chiral invariant functional"

2) "Bosonization of conformal anomaly and induced gravitation" (D.V.Vasilevich and Yu.V.Novozhilov, TMF 73 (1987))
In this paper an effective action in the low energy region of the Einstein type is obtained using bosonization of the conformal anomaly with only one free dimensionful parameter, the boundary of the low energy region Λ.
The low energy functional integral is taken as

$$Z^{\Lambda}(e^{\alpha}_{\mu}) = \det(1 - P_{\Lambda} + P_{\Lambda}\hat{D}P_{\Lambda})$$

where P_{Λ} - is a projector onto the low-energy region and $\hat{D}$ - the Dirac operator in the curved space

$$\hat{D} = -i\gamma^{\alpha}e^{\mu}_{\alpha}(\partial_{\mu} + (1/4)\omega_{\beta\delta}\gamma^{\beta}\gamma^{\delta})$$

The conformal anomaly has a form

$$\mathcal{A}(x) = e^\alpha_\mu(x)\frac{\delta \ln Z_\Lambda}{\delta e^\alpha_\mu(x)} = -\mathrm{tr} < x|P_\lambda|x >=$$

and after some calculations

$$\mathcal{A}(x) = \sqrt{g}\Big(-\frac{\Lambda^4}{8\pi^2} - \frac{\Lambda^2 R}{48\pi^2} + \{R^2\}\Big)$$

where $\{R^2\}$ are terms quadratic in the Riemann tensor R already known before. By integration of the anomaly the anomalous action is derived and then by the general bosoniztion technique the low-energy effective action in the Minkowski space. Assuming the external gravitation field to be weak the authors find the effective functional in the form

$$Z_{eff}(e^\alpha_\mu) = \int D \ln \Omega$$

$$\exp\Big\{i\int d^4x\sqrt{-g}\frac{R - 2\lambda_{tot} - \Omega^2 R - 6\Omega\partial^2\Omega + 2\omega^4\lambda_{tot}}{15\pi G_{tot}}\Big\}$$

where the renormalized parameters are expressed from the bare ones as

$$G_{tot}^{-1} = G_0^{-1} + \frac{\Lambda^2}{6\pi}, \quad \frac{\lambda_{tot}}{G_{tot}} = \frac{\lambda_0}{G_0} - \frac{\Lambda^4}{4\pi}$$

Here G_0 and λ_0 - are bare Newton and cosmological constants The authors conclude "The boundaries of the low-energy region are to be determined by considerations external to this approach, for instance from the requirement of cancellation of the bare cosmological constant which appears after compactification of multidimensional models. Note that the kinetic term for field Ω enters the action with the correct sign".

7. Chiral parametrization of the gluonic field This is the last topic with which Yu.V. was occupied in his life time. It is treated in two papers by Yu.V.Novozhilov and V.Yu.Novozhilov published in 2006 and 2008. We shall make a short presentation of the 2008 paper "Chiral parametrization of QCD vector field in SU(3)" (Mod. Phys. Lett. A (2008)).

This topic was initiated by L.D.Faddeev with co-authors in pursuit of a proper parametrization of the gauge field with topological properties adequate for constructing solutions to study the vacuum structure and confinenement. The 2008 paper is an extention to SU(3) of the chiral parametrization proposed in the 2006 for SU(2). A chiral colour field is introduced, gluons are chirally rotated and vector component of rotated gluons is defined on condition that no new variables appear with the chiral field. Massless fermions are placed in external vector and axial vector fields V and A and local chiral trsnsformations of left and right quarks are introduced: $q'_{(L,R)} = U_{(L,R)} q_{(L,R)}$. The fields are transformed $V, A \rightarrow V^U, A^U$.

Next a chirally invariant combination V^Ω of V and V^U is constructed which possesses a property

$$(V^U)^U = V^U$$

This field is parametrized as

$$V_\mu^\Omega = C_\mu(m - 1/3) + G_\mu + \frac{1}{2} m \partial_\mu m$$

where C is an Abelian gauge field, G is a $U(2)$ component of V^Ω and m one of the three unit matrices satifying $m^2 = 1$. The corresponding axial field $\hat{A}$ is determined from the decomposition

$$V = V^\Omega - \hat{A}$$

The effective action is constructed as

$$W_{eff} = -i \ln \left\{ Z_q(V^{\Omega}, \hat{A}) Z^{-1}(V, 0) \right\}$$

where Z_q is the quark part of the generating functional. It consists of two parts: the Wess-Zumino-Witten term W_{WZW} and the term coming from the anomaly W_{an}. The last term has the same structure as in the SU(2) case. The explicit expression for W_{WZW} is presented in the end of the paper.
The authors conclude saying " It is shown that in the chiral parametrization of the QCD vector field for $SU(3)_C$ an effective colour space is defined by the Hermithean colour field $U = m$ representing an orbit through hypercharge SYS^{-1}. The parametrization contains an Abelian field directed along m and an U(2) field G, which commutes with m. The axial component A anticommutes with m and belongs to the tangential bundle of CP^2. Thus the colour parametrization restricts the color space ascribed to gluons in the absence of quark chiral color."

8. Conclusion

In his life Yu.V. has published about 200 papers. We were able here to briefly discuss only a very smal part of them. They vividly illusttate the talent of Yu.V., his versatility and wide scope of his ideas.
This extraordinary creativity, great erudition, sharp intelligence together with personal charm and benevolence always made Yu.V. a center of a circle of young theoreticions ready to work in the exciting field of elementary particles. From the start Yu.V. was surrounded by his pupils, which under his guidance tried to understand a constantly changing world of particle physics. From him they were inheriting perseverance, self-criticism, capabilities to study scientific literature, high mathematical culture and clarity of motivation and perspectives. He has created an acknowledged school of theoreticions, many of whom continue working in the field. Among his pupils 4 heads of chairs, 15 doctors of science, more than 30 candidates of science.

At his lectures many leading theoreticions became aquainted with their future working field. Among them academicians L.D.Faddeev, V.A.Matveev and L.N.Lipatov, member-corr. of the academy V.N.Gribov.

Yu.V. was an outstanding organizer of science, a talented administrator. He created and during a long period led the chair of nuclear and elementary particles in LGU, one of the first and even now few chairs specializing in quantum field theory, theory of elementary particles, high energy physics and relativistic nuclear theory. As mentioned, he was vice-rector for scientific affairs of LGU, dean of the physical faculty. In 1973-1981 he was carrying out a highly important work in UNESCO.

All these qualities were a source of great respect and gratitude to Yu.V. from the physics community in Rissia and abroad. Memory of his brilliant personality will never die and continue in the work and deeds of his pupils and friends throughout the world.