

CONFERENCES AND SYMPOSIA

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International Conference 'Quantization, Gauge Theories, and Strings' devoted to the memory of Efim Samoĭlovich Fradkin (Moscow, 5 – 10 June 2000)

The International Conference 'Quantization, Gauge Theories, and Strings' devoted to the memory of Efim Samoĭlovich Fradkin was held in Moscow from June 5 to 10, 2000. The following contributions are presented below:

1. **Voronov B L** (I E Tamm Department of Theoretical Physics of the P N Lebedev Physical Institute of the Russian Academy of Sciences, Moscow) "On the International Conference 'Quantization, Gauge Theories, and Strings'';
2. **Ginzburg V L** (I E Tamm Department of Theoretical Physics of P N Lebedev Physical Institute of the Russian Academy of Sciences, Moscow) "About Efim Fradkin";
3. **Feĭnberg E L** (I E Tamm Department of Theoretical Physics of P N Lebedev Physical Institute of the Russian Academy of Sciences, Moscow) "E S Fradkin as a person".

Brief presentations of the reports presented are given below.

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On the International Conference 'Quantization, Gauge Theories, and Strings'

B L Voronov

The International Conference 'Quantization, Gauge Theories, and Strings' devoted to the memory of Efim Samoĭlovich Fradkin was held in Moscow from June 5 to 10, 2000.

The conference was organized by the I E Tamm Department of Theoretical Physics of the P N Lebedev Physical Institute of the Russian Academy of Sciences and was sponsored by the Russian Academy of Sciences; INTAS; the Russian Foundation for Basic Research; the RF Ministry of Industry, Science, and Technology; the International Center for Fundamental Physics in Moscow; Photon Physics; and Visson Enterprises Ltd. The conference was held in the Conference Complex of the Central Tourist House on Leninskiĭ prospect in Moscow.

Devoting the conference to the memory of their colleague and teacher, the outstanding Russian theoretical physicist Efim Samoĭlovich Fradkin, the organizers believed that the best way to pay homage to the memory of a scientist is to hold a conference embracing the fields of research that have been the subjects of his interest and fruitful activities. It turned out that the conference touched upon almost all the leading trends of modern theoretical and mathematical physics concerning the structure of matter and fundamental interactions: the string theory in the modern broad understanding (M-theory), including the higher-spin and conformal theories; the problems of quantization in a wide variety of modern approaches and formalisms as applied to diversified systems — from one-particle to field ones; advances in the traditional quantum field theory, in particular, new aspects of gauge theories; the theory of gravitation and cosmology; high-energy physics and the physics of specific interactions, including quantum chromodynamics at high densities and temperatures and quantum electrodynamics in external fields.

The invitation to participate in the conference devoted to the memory of E S Fradkin everywhere met a lively and thankful response. As a result, there were about 150 participants, nearly 70 foreigners among them. The attendance of the conference was fairly representative and included many leading specialists in different fields. More than 130 talks were given. The sessions as a rule were organized as follows: plenary invited talks were made in morning hours, and the rest of the time was given to parallel section meetings.

The morning plenary session of the first day was memorial and was held at the P N Lebedev Physical Institute (FIAN). V L Ginzburg and E L Feĭnberg presented a narration about the life and personal qualities of E S Fradkin. The young years of Efim Samoĭlovich, which he spent at the so-called 'Object', were described by Yu A Romanov. L Brink (Sweden) and P Nieuwenhuizen (USA) shared their impressions and reminiscences about 'meetings with Efim Fradkin'. Efim Samoĭlovich's life began with the tragedy of the first months of the Great Patriotic War, when almost all his family remained on the occupied territory and died at the hands of nazis. Then he served first as a solder and, on recovery after a bad wound, as an officer in the Field Forces. When the war was over, he took a brief university course in Lvov and, finally, in 1948 found himself tied forever to the Theoretical Department of FIAN. Since then his life was full of tireless contemplation, calculations and discussions of the most topical and sophisticated problems of theoretical physics with his disciples and colleagues. He also took a lively and wise interest in all aspects of life. 'Fradkin's school' and the thankful memory of people will long be a memorial to him.

In a brief review we failed not only to mention all the reports, but even dwell on all the subjects discussed at the conference. That is why it was decided only to give a brief account of some reports to outline the themes of the conference. The reports are presented in the same sequence as the subjects of the conference listed above. The blanks of such a review will be filled in by the proceedings of the conference to appear in the near future at 'Nauchnyĭ Mir', Moscow.

Uspekhi Fizicheskikh Nauk **171** (8) 869–876 (2001)
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Experiments carried out within modern elementary particle physics do not challenge decisively the existing concepts of the structure of matter and of fundamental interactions. The string theory is rather a response to intra-theoretical challenges or a kind of the self-development of the theory. It radically changes our idea of space – time (additional spatial dimensions) and matter (extended fundamental objects) on small scales and has yet to find an experimental confirmation. About 60 talks concerning strings were given.

The string theory holds onto its claim to be the 'theory of everything', but it has been enriched by new ideas, and so its contents have changed radically. The current state of the string theory was reviewed by J Schwarz (California Institute of Technology). The deep and delicate links among the five known superstring theories (which have up to now been thought of as different theories) in the form of so-called duality relations, which imply that one theory is a limiting version of another (limiting transitions with respect to the theory parameters are meant), have already been understood. It seems a natural idea to unify all these theories within the framework of one fundamental theory referred to as the M theory. The M theory is still to be constructed, and only some fragments of it are known. In particular, the five known superstring theories are considered to correspond to different vacuums of the M theory. It is also assumed that the low-energy limit of the M theory should be eleven-dimensional supergravity. Along with fundamental strings, the theory contains nonperturbative (soliton-like) extended objects called p-branes. They can be represented as $p+1$-dimensional surfaces (p spatial and one time dimension) in a multidimensional enveloping space – time. The p-branes are 'charged' in a certain way, the charges being sources of the corresponding gauge fields (generalizing the Maxwell field). The ends of fundamental strings may lie at p-branes. New physics is associated with p-branes: they underlie cosmological models ('scenarios') alternative to the compactification of all additional dimensions (see below the Randall – Sundrum model and the report of V A Rubakov).

Developing the idea of duality, C Hull analyzes the string theory compactified in a certain way (M theory) in the limit of the scale parameter tending to infinity. All excitations become massless in this limit, and a large number of unbroken symmetries occur. The resultant theory appears to be a certain six-dimensional superconformal theory with an unexpectedly high supersymmetry — a new fragment of the M theory.

A theory dual to the $N=4$ supersymmetric Yang – Mills theory is the superstring II B theory with weak coupling in $AdS_5 \times S^5$ space – time (a five-dimensional anti-De Sitter space $\times$ a five-dimensional sphere) with a so-called Ramond – Ramond charge (a string on the R – R background). Even the construction of string action on such a background is a difficult task, which was solved only fairly recently (Metsaev and Tseĭtlin). In his talk, A A Tseĭtlin presented calculations of quantum corrections to this action, which prove to be associated with the vacuum average of Wilson loops in the dual Yang – Mills theory in the limit of strong coupling and high dimension of the gauge group.

Further advances in this and other directions are associated with the construction of Green – Schwarz methods for covariant superstring quantization, which have not existed up to now. In this respect, the talk by N Berkovits, who proposed a method for covariant quantization, deserves attention. This is a new version of the Green – Schwarz formalism including an additional commuting spinor field, which obeys certain constraints.

The fundamental microscopic degrees of freedom of the M theory are not yet well known. Their manifestations may be the so-called BPS states, soliton-like solutions of supergravity with a certain compactification of additional dimensions; they can be included into supermultiplets of matter. They are assumed to correspond to some branes of the nonperturbative string theory. B de Witt considered nine-dimensional $N=2$ supergravity interacting with certain (so-called KKA and KKB) BPS states. This leads to a twelve-dimensional field theory with a maximum supersymmetry, three compact dimensions, but without Lorentz invariance. A special decompactification limit yields eleven- (or ten-) dimensional supergravity and BPS states are treated as supermembrane states, or super – Kaluza – Klein states. In this connection, interest in quantum corrections to the characteristics of extended objects and generally in the status of BPS states at a quantum level has been revived. P van Nieuwenhuizen discussed the calculation of quantum corrections to the mass and the central charge of the supersymmetric $D2$ kink. The initial controversy in the results for the kink mass obtained by two different regularizations is ultimately eliminated after the mass formula is specified and fine boundary effects are included. The quantum anomaly for the central charge is calculated, and it is shown how the BPS restriction is restored at the one-loop level.

The discussion of eleven-dimensional supergravity, i.e., the assumed low-energy approximation to the M theory, has taken a special place. Two approaches to the formulation of this theory are known, namely, the covariant and the light-cone formalisms, and both were presented at the conference. M Cederwall considered the effective dynamics of the theory in an explicitly covariant and supersymmetric formulation. The weakening of the restrictions on the superspace torsion proposed earlier was shown to lead to the standard equations of eleven-dimensional supergravity. A possibility of extending the covariant superfield formalism to a theory with higher (R^4) derivatives was discussed. A superfield (without constraints) light-cone formulation of eleven-dimensional supergravity was given in the talk by R R Metsaev. By analogy with the ordinary string theory, this particular formulation is expected to admit a natural extension of the M theory. All the four-point functions on the mass shell, invariant under linear supersymmetries, were found.

The idea that our Universe is a 3-brane embedded in a multi-dimensional space – time compactified in a special manner has been actively discussed in recent years. Sophisticated as it is, such a scenario is welcomed by the M theory. Interest in this idea increased greatly after Randall and Sundrum showed that gravity in such a world would be effectively four-dimensional if the geometry of the enveloping space was the AdS_5 geometry. A new lesson is the possibility that additional spatial dimensions should not necessarily be compactified (remarkably, such a possibility was discussed by V A Rubakov and M E Shaposhnikov as far back as in 1983). The potential measurability of the predicted power-like corrections to the Newton law draws special attention to this scenario. A supersymmetric version of the realization of the described scenario by way of a special $AdS_5 \times S^5$ compactification of II B supergravity and embedding of a 3-brane into an anti-de-Sitter AdS_5 space was discussed by K Stelle. A mechanism was proposed that allows by-passing the 'no go' theorems considered in a talk by R E Kallosh.

The development of the theory of higher-spin gauge fields in a four-dimensional space – time was reviewed by M A Vasil'ev. In the historical aspect, the main emphasis was laid on the contribution made by E S Fradkin, beginning with his first scientific paper devoted to a spin-5/2 field theory. The report described the infinite-dimensional higher-spin symmetry algebra obtained in collaboration with E S Fradkin, as well as the action specifying cubic interactions of higher-spin gauge fields with one another and with gravity. A self-consistent formulation of the nonlinear equations of motion of massless fields of all spins was given. A new result in the development of the conformal theory of higher-spin gauge fields proposed by Linetskiĭ and Fradkin was announced. This result is an attempt to reformulate the constraints of the conformal theory of higher-spin gauge fields in the form of a covariant constancy condition. Special attention was paid to deep parallels between the properties of the higher-spin gauge field theory and the superstring theory. The speaker stressed that such outwardly dissimilar properties of the theory of higher-spin gauge fields as the necessity to introduce infinite sets of fields with unlimitedly increasing spins, the appearance of higher derivatives in the interaction vertices for higher-spin fields, and the key role of the anti-de-Sitter geometry for the construction of gauge-invariant interactions of higher spins are put together by the fact that the algebras of higher-spin symmetries are algebras of quantum oscillators.

V N Zaĭkin and M Ya Pal'chik summed up the progress achieved within the conformal field theory, the ideas and conclusions of which were elaborated in cooperation with E S Fradkin; this cooperation continued until the last days of his life. The main idea consists in an extension of the results obtained in two-dimensional theories to the case of an arbitrary dimension. It was noticed earlier that in both a two-dimensional space and a space of an arbitrary dimension, secondary tensor fields ('descendants') with certain dimensions appear in the operator product of the fields of the energy – momentum tensor and matter. The requirement that such fields should be absent leads to algebraic equations for anomalous dimensions of the fields of matter and to differential equations for Green functions. However, as distinct from the two-dimensional case, in a D-dimensional space the secondary fields in the above-mentioned operator product appear only under certain conditions. For a scalar theory with a non-Abelian global symmetry, secondary fields were shown to appear only if anomalous operator summands (analogues of a central charge) occur in the operator product of two conserved currents. The conditions for the appearance of such anomalous operators, their coupling constants, as well as the Green functions involving these operators were found. The Ward identities for the Green functions of two conserved currents were investigated.

The problems of quantization and the traditional quantum field theory were touched upon in more than 40 talks.

A new and more general formulation of theorems on the connection between spin and statistics and on the CPT symmetry was proposed by M A Solov'ev. This approach can be applied to quantum field theories with an arbitrary degree of nonlocality. Such theories can arise as effective field theories following from the string theory (M theory). It has been proved that a necessary condition for the validity of standard theorems is a fast decrease (faster than an exponential of order one) of the smoothed field commutators with the increase of the space-like separation of arguments. The mathematical apparatus used in this context is a development of the Schwarz distribution theory and the Sato – Martineau hyperfunction theory. It is also used to describe the operator realization of gauge theories with singular infrared behavior in indefinite-metric spaces and in the covariant gauge of the general form (to which the talk of A G Smirnov was devoted).

The old problem of canonical quantization of the (pseudo-) classical theory of a relativistic particle in external electromagnetic and gravitational fields again and again calls for research. The main difficulty encountered up to now was that in arbitrary external fields (which do not produce pairs) the wave functions did not satisfy the Klein – Gordon equation. D M Gitman showed in his talk how one could overcome this difficulty by modifying the quantization scheme. The proposed modification is based on using an initially reducible representation of canonical commutation relations and a special construction for the Hamiltonian. The quantum mechanics constructed reproduces literally the one-particle sector of quantum field theory.

R Marnelius discussed the methods of integration of infinitesimal gauge transformations of the general form that are generated by first-class constraints and form an infinite-dimensional open algebra. The generating equations of finite transformations are formulated in an extended phase space including ghosts and Lagrange multipliers to constraints in terms of a total BRST operator. The compatibility of the composition properties of finite transformations is provided by the master equation formulated in terms of quantum antibrackets, which are an operator extension of the classical antibrackets of the Batalin – Vilkovisky formalism. The results are extended to an $Sp(2)$-symmetric formulation, which equally includes ghosts and antighosts.

The possibility of consistent dynamics of a system of a finite number of spin-2 fields was discussed by M Henneaux in the framework of the BRST approach, under the following assumptions: the Poincare invariance; a space – time dimension higher than 2; in the limit of free fields a set of spin-2 fields can be described by the sum of Pauli – Fierz actions (linearized Einstein actions); an exact action contains no more than two derivatives with respect to coordinates. The speaker shows that the total action has the form of the sum of the Einstein actions with possible cosmological terms and the Pauli – Fierz actions, one for each field. Cross interactions of different fields are absent. The result obtained agrees with the experimental fact of the absence of other spin-2 fields, except for the gravitational field (because the gravitational field must interact with any matter).

As demonstrated by A A Slavnov, the gauge theories that contain anticommuting fields (e.g., ghosts) in the standard formalism, can be formulated in terms of purely boson fields. This is motivated by the higher efficiency of computer calculations of the determinants represented by functional integrals over boson fields, compared to direct calculations. A purely boson formulation of the four-dimensional Yang – Mills theory is presented, which is a special reduction of the five-dimensional theory. A bosonized version of quantum chromodynamics with two flavors on a lattice is also considered.

A special topic of the last years is related to attempts at a nonperturbative consideration of supersymmetric gauge field theories on the basis of verisimilar hypotheses on the spectrum structure and analytical properties with respect to the parameters of the theory (coupling constants and vacuum condensates). A I Vaĭnshteĭn formulated a new approach to the study of vacuums in $N = 1$ supersymmetric gauge theories, which is based on a 'soft' violation of the $N = 2$ supersymmetry and on the use of the properties of exact Witten – Seiberg solutions for $N = 2$ supersymmetric gauge theories. The main nontrivial contribution to the exact values of vacuum condensates turns out to be made by instanton corrections to the Affleck – Dine – Seiberg superpotential. This approach allows, in principle, an examination of electric charge confinement by analogy with the theory of superconductivity and electromagnetic duality. A more thorough consideration of confinement was given by A Yung, who in particular attempted to draw an analogy between the expected properties of 'non-Abelian' confinement in quantum chromodynamics and the above-mentioned 'Abelian' confinement in supersymmetric gauge theories. A V Marshakov discussed the remarkable ralation between the Witten – Seiberg theory and the theory of integrable systems: Witten – Seiberg singular curves corresponding to $N = 1$ supersymmetric gauge theories simultaneously describe soliton solutions of certain integrable systems, which allows an easy calculation of the effective coupling constants and the tensions of strings of gauge theories (the tensions are simply equal to soliton phases).

The modern quantum theory of gravity is multi-faceted. On the one hand, it is closely related to the hypothetical fundamental string theory. On the other hand, contemporary cosmology, which has a high experimental status, requires that this theory provide a theoretical explanation of observational data. This versatility of today's gravitational science found an adequate reflection at the conference, where three principal directions of this science were presented — quantum inflationary cosmology, 'brane-world scenarios' following from the string theory, and the theory of quantum black holes.

A D Linde gave an extensive review of the inflationary theory, from its birth to the last advances referring to the post-inflation preheating stage of cosmological evolution. He specially stressed the role of the new effective mechanism of matter production in the Universe at the preheating stage due to the parametric resonance related to the interaction between matter excitation modes and the inflaton, which begins at the moment when the inflaton field disappears (at the post-inflation stage of inflaton oscillations). A O Barvinskiĭ presented his theory of quantum effective mean-field equations for the metric and matter in inflationary cosmology, with special emphasis on the setting of the Cauchy problem for these equations: the Cauchy data should be extracted from the quantum state of the Universe. An essentially new element of these equations is the allowance for quantum fluctuations of a uniform scalar mode, which is the main collective variable of the quantum cosmological model; its peak-like initial distribution explains the comparatively small characteristic energy scale in the quantum-created inflationary Universe, which has here the same order of magnitude as in grand unified theories.

V A Rubakov devoted his talk to the gravitational aspects of brane-world scenarios. He discussed (i) the origin of long-range forces on a *3*-brane immersed in a five-dimensional space – time with a noncompact additional dimension, in particular, an interesting mechanism of graviton metastability in the Gregory – Rubakov– Serebryakov model, which is an extension of the Randall – Sundrum model, and (ii) the scalar (repulsive) origin of gravitation, induced on a brane, at superlarge distances. The picture was completed by S N Solodukhin, who asserted that the energy – momentum tensor in the Einstein equations induced 'from the bulk' on a brane (i.e., according to the theory in an enveloping space) contains both higher-order terms in curvature and a holographic energy – momentum tensor following from the AdS/CFT duality (i.e., the correspondence between the five-dimensional theory of (super) gravity in an anti-de Sitter space and the four-dimensional conformal field theory on its boundary).

M Z Iofa discussed the form of the effective action, the equations of motion following from this action, and their solutions in the superstring theory with allowance for string loop corrections. For the considered compactification of the heterotic string theory to four dimensions, the effective action possesses a local $N = 2$ supersymmetry. The solution to the equations of motion is considered, which describes a magnetic black hole at the tree level of the string perturbation theory. String loop corrections to the tree solution were found using the $N = 2$ supersymmetry of the effective action. The possibility of smoothing the singularity of the tree solution by string loop corrections is considered.

A series of talks were devoted to the problems of quantum chromodynamics (QCD) and the theory and phenomenology of strong interactions.

Among the most challenging problems is the construction of the theory of quantum-field non-Abelian systems at high temperatures and densities. J-P Blaizot suggested a new approach to obtaining a high-temperature asymptotics for the entropy of a quark – gluon plasma. The approach is based on skeleton expansions in (self-consistent) Schwinger – Dyson equations for temperature Green functions and on taking into account, along with the leading contributions from quasi-particles with energies of the order of T, also the nonleading contributions from soft modes with energies of the order of gT, with the help of a nonlocal effective action. In spite of the uncertainties related to the accuracy of the exploited approximation, an inspiring circumstance is the coincidence of the temperature dependence obtained for entropy with the results of calculations on a lattice.

New results obtained in the framework of the Wilson renormalization group approach to the description of the quantum evolution of parton correlators were discussed by A V Leonidov. An achievement is a universal derivation of the known linear and nonlinear QCD evolution equations in the leading logarithmic approximation in transverse momentum and energy, respectively. Both asymptotics are considered using a unified effective action and the same starting tree-level configuration in the QCD parton model. Explicit formulas are presented for the exact kernel of the general nonlinear equations of QCD evolution equations referring to two different prescriptions (two ways of handling the zero modes) for a gluon propagator; the description of nonlinear effects depends on the choice of this prescription.

I M Dremin discussed the multiplicity distributions in quark and gluon jets, which are predicted on the basis of the exact equation for the QCD generating functional. The high quality of the available experimental data makes it possible to perform a detailed testing of perturbative calculations and to estimate nonperturbative contributions. In another talk, I M Dremin considered one of the most powerful modern methods of event-by-event analysis of multiple production processes based on the use of wavelet transforms. This method was applied to nucleus – nucleus collisions and made it possible to reveal ring-like structures testifying in favor of Cherenkov-radiation-type effects of a gluon in a chromatic medium.

Problems of experimental diagnostics of a quark – gluon plasma that can be produced at early stages of collisions of ultrarelativistic heavy ions, based on using photon and dilepton signals, were considered by I V Andreev and I I Roĭzen, respectively. According to the standard hydrodynamic description of nucleus – nucleus collisions at high energies, a conversion of the quark – gluon plasma into hadrons in the course of the dynamic expansion must be accompanied by the emission of photons with specific spectral and correlation characteristics. The specific dilepton signal could be a manifestation of the hypothetical 'pion – valon phase', which is intermediate between the phase of the pure quark – gluon plasma and the confinement phase and is characterized by the violation of the chiral symmetry and the formation of constituent quarks (valons). Taking the valon phase into account would probably make it possible to describe the deficiency of dileptons predicted by the standard scenarios, which was observed on the SPS accelerator in CERN.

The effects of quantum electrodynamics (QED) in strong external fields in various media and with the presence of boundaries still remain very interesting in view of the new experimental possibilities.

A review talk by G Soff et al. outlined the modern theoretical and experimental status of QED in the fields of strongly ionized heavy ions. The results of nonperturbative calculations of the Lamb shift of energy levels in a hydrogen-like uranium ion are given. The relative accuracy of calculations of the ground state energy, reached by now, is 10^{-6}, which will allow a more detailed verification of fine QED effects in strong ion fields in the near future.

The study of the electroweak phase transition in a constant electromagnetic field and its relation to baryogenesis in the framework of the Standard Model was reported by V Demchik and V Skalozub. The consideration was performed in terms of the self-consistent effective potential for a scalar and an electromagnetic field at a finite temperature, calculated with allowance for one-loop and ring diagrams. The fundamental-particle masses were assumed to be equal to their experimental values, and the Higgs boson mass was assumed to lie in the range 75 – 115 GeV. For magnetic field strengths $H = 10^{22} - 10^{23}$ G, a numerical calculation established the presence of a first-order phase transition, but the jump of the order parameter was small. For stronger fields, a crossover was observed. A conclusion was drawn that, in the Standard Model, a hypermagnetic field does not generate a strong phase transition and the conditions for baryogenesis are not met.

K Milton reviewed various aspects of the Casimir effect, as applied to the scalar, electromagnetic, and fermion fields. The dependences of this effect on the geometry and space dimension were analyzed. The most thorough consideration was given to the electromagnetic Casimir effect, in particular, its relation to the Van der Waals forces and its application to dielectrics and semiconductors of various shapes. A possible connection of this effect with sonoluminescence, whose physical origin still remains enigmatic, was also examined. The calculations were performed simultaneously by the traditional method and by the Green function method.

A possible approach to the problem of absorption in quantum mechanics, based on the use of singular attractive potentials, was discussed by J Audretsch and V D Skarzhinskiĭ. Different absorption models were realized by a special choice of exact solutions to the stationary Schrödinger equation. The motion of a charged particle in the Aharonov – Bohm potential and in an axisymmetric potential proportional to the inverse square of the distance to the axis was considered at length.

S Fulling proposed a new scheme of Feynman integral approximation for the particle propagator in an external field. The proposed approximation procedure based on the Wigner – Kirkwood expansion over a short but finite time interval rapidly converges, so that the division of the total time interval even into a small number of sub-intervals provides a good approximation.

The general opinion of the participants was that the conference was well organized and a success.

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About Efim Fradkin [1]

V L Ginzburg

For many years, I have already not been occupied with the problems that are the subject of the present conference. But it was organized in the memory of Efim Fradkin, and therefore I decided to give a talk. The point is that I have known Efim (Fima, as we used to call him) longer than anyone present. I shall tell later how and why I met Fima for the first time. And now I shall begin with his biography [2].

Efim Samoĭlovich Fradkin was born on November 30, 1924, in the provincial Belorussian town of Shchedrin located within the so-called 'Jewish pale'. Not everyone in this audience, especially the foreigners, know what this means. In tsarist Russia, that is, before 1917, Jews had the right to reside only within certain limited territories. Exceptions were only made for christened Jews, rich merchants, and so on, and the Fradkins belonged to none of those groups. Theirs was a poor family with many children. Their life was hard, and the father, a former rabbi, was subjected to repression and died in prison. Fortunately, no racial limitations or, simply speaking, State-encouraged anti-Semitism existed in the USSR in the 1930s, and Fima could enter Minsk University in 1940. He studied there for only a year before the beginning of the Great Patriotic War, that is, before June 22, 1941. Fima managed to leave Belorussia before it was occupied, but his mother, two sisters, and a younger brother were killed by the Nazis. Of all the family, only Fima and his elder brother, who was in the army, could survive. Fima was in evacuation for some time, in Bashkiria, worked as a school teacher, and at the beginning of 1942 voluntarily joined the army as a common soldier. He was badly wounded near Stalingrad, and after the hospital he was sent to an artillery school. Then he took part in combat again,

[1] A talk at the Conference 'Quantization, Gauge Theory and Strings' (dedicated to the memory of Professor Efim Fradkin) held on June 5, 2000.
[2] I shall partly repeat here what I wrote in paper [1] published in the collection [2] devoted to E.S. Fradkin's 60th birthday. See also the obituary [3].

but this time as an officer. He was rewarded for his services in battles. Along with his service in the army, Efim studied by correspondence at the Lvov University from 1945. But only after the demobilization in 1946, he could study normally and he graduated from the university in 1948. He even wrote two diploma theses. One of them, which unfortunately was not published, was devoted to the effects of an electric field upon some transitions in atoms. In his second diploma thesis Efim considered the behavior of a relativistic particle of spin 5/2. He chose this subject himself after he read in a library my paper analyzing spin 3/2 [4]. He wanted to extend my consideration to the case of a higher spin (this paper was later published [5]).

In Lvov, there were apparently no specialists in relativistic quantum theory, and that is why Fima, decided to move to Moscow in 1947, being entitled to do this as an ex-serviceman. I do not remember exactly, but we may have exchanged letters before that. However, I remember well how Fima appeared in FIAN (the P N Lebedev Physical Institute of the USSR Academy of Sciences) in order to speak to me. We met in the old FIAN building in the Miusskaya square, now occupied by the M V Keldysh Institute of Applied Mathematics. I had a tiny office, some walled-off cubbyhall. And there I saw a slender short youth dressed in a greatcoat. I gave him the only chair in the room and sat down myself on the table. Fima told me later that he had been amazed: he thought he would meet a dignified and pompous professor, for in Lvov, which had been a Polish town before 1939, there probably remained such a professorate. I was then 31 years old and was neither dignified nor pompous. None of us at the Theoretical Department of FIAN were dignified nor pompous, and the founder of our department Igor Tamm was not an exception, although he was already 52 at that time. The atmosphere at the department was friendly and democratic. A detached view would of course be more exact, whereas I have worked at the department for 60 years (since 1940). But I would permit myself to express the opinion that our department is not typical, and during all these 60 years there was only one serious conflict caused by the dismissal of one of the research workers. What is typical of our department is respect for youth and the impossibility of putting one's name on another person's paper. In particular, Fima was my post-graduate student and we frequently discussed various issues, but we have no joint publications.

I E Tamm and I appraised Fima's abilities and recommended that he should enter the post-graduate course at FIAN. But this was not at all easy because State anti-Semitism already came to reign in this country. Fima was accepted to the post-graduate course with great difficulty in 1948, and I think only because he was a war veteran and had been wounded. It seems to me, by the way, that Fima first appeared at our department in late 1947. As far as I understand, Fima was happy (he told me about it himself [2]), for after so many years of very hard life he finally had found himself in the right place. And he 'responded' with selfless work; he obviously believed, and not without reason, that much time had been lost. Efim's capacity for work, his devotion to science and work attracted attention, although none of us was idling. In addition, Fima was a bachelor, and it can be said that all his effort was directed to work. He was first of all interested in fundamental questions, and it was not accidental that he had set himself to the spin theory even before he came to FIAN. The young research workers and post-graduate students of the department, including Andreĭ Sakharov (he was three years senior to Fima, having entered the post-graduate course of the department in 1945, and defended his candidate's dissertation in November, 1947), made good company for him.

Unfortunately, or maybe fortunately, because this played a positive role in his fate, Efim was unable to give all his strengths to the solution of fundamental problems for several years. The point was that in 1948 or 1949 he was included in the group headed by I E Tamm and admitted to secret work (the content of this work became known only in 1990 (!) after the death of A D Sakharov; the work was aimed at creating a hydrogen bomb). For several years E Fradkin was engaged in a number of problems, viz., transport processes in hot plasmas [6], hydrodynamics [7], and the theory of turbulent mixing [8] (these studies were published with a delay after their content was declassified). But, as I have already mentioned, in his heart Efim longed for another kind of problem and published not only the above-mentioned paper about spin 5/2 [5], but also a paper about the reaction of radiation in the classical theory of electron [9]. The main thing is that he also found time to follow the current literature on elementary particle physics, as this field was then called. He was also interested in quantum statistics. Beginning with 1953 or 1954, Efim could give almost all his strengths to investigations in these particular fields (quantum field theory and quantum statistics). At that time he also began a 'new life' in another respect — in 1955, Fima got married. This was a very happy marriage. The whole department was present at his wedding, which I described in paper [1], and I would not like to repeat myself here.

From 1955 up to his death (he passed away a year ago, on May 25, 1999), Efim, a person of studious habits, was completely absorbed in his work. The only obstacle in his way was his poor health, which had been badly affected by his hard childhood and youth and the wound. In 1955 or so, I practically stopped working on the above-mentioned problems, which were Efim's prime concern. That is why it would be out of place if I dwelt here on the results of his work on quantum field theory and quantum statistics, the more so as it was done in the collection of papers [2], in the obituary [3], and will certainly be reflected by the present conference.

I would like, however, to make two more remarks.

Here is what A.D. Sakharov wrote in his *Reminiscences* ([10], p. 108): "Of all our company, Fradkin was the only one to have reached the level of a highly professional 'forefront' theoretical physicist, of which we all had dreamed. He has great achievements in almost all basic directions of quantum field theory (the Green function method in renormalization theory, functional integration, gauge fields, unified theories of strong, weak, and electromagnetic interactions, the general theory of quantization of systems with constraints, supergravity, string theory, etc.). He was the first to discover the 'Moscow Zero' independently of Landau and Pomeranchuk. Many of the results obtained by Fradkin are classical. Fradkin has no equal in methodical questions." I think that this is a just appraisal. And, incidentally, during Sakharov's exile in Gor'kiĭ Efim visited him several times and helped him in all possible ways.

Efim Fradkin was a brilliant representative of a whole generation of Soviet physicists, who were involved in science research with great enthusiasm. Meanwhile, the financial conditions of our life were rather bad according to American and European standards. In the Stalin period, particularly during the 'cold war', only the chosen few could go abroad.

Since 1947, the persecution of so-called cosmopolitans began, the remarkable *Journal of Physics USSR* was no longer issued, and our Russian periodicals were not translated into English. I do not even mention the complete lack of freedom of speech under the totalitarian regime. But we worked, I repeat, with great enthusiasm to the amazement of some of our foreign colleagues. It seems to me that it was in 1956 that a large group of such highly qualified theoretical physicists, of whom Sakharov wrote, came to the USSR for the first time after many years. F Dyson was among them. After he returned home, in one of his papers he specially commented on what I have said about (the enthusiasm of Soviet colleagues) and explained it as follows: "They have nothing else" (I quote from memory). In other words, 'everything has gone to science', and in such a way they can forget about their hard life. This is a profound remark (here Efim is a vivid specimen) and for a long time I believed it to be quite correct [3]. But now I no longer consider such an explanation to be exhaustive.

Indeed, after the fall of the villainous bolshevik Lenin–Stalin regime in Russia we now have the freedom of speech and the freedom of migration. Research workers, as all citizens, can go abroad practically unlimitedly and meet their colleagues all over the word or correspond with them through either ordinary or electronic mail. Our main journals are translated into English. Of course, there are still many enthusiasts, who give all their strengths to science. But the tone, the general spirit is now quite different. A lot of young people leave science (say, for business), others go abroad or work reluctantly and do not attend seminars regularly. Elderly people often think that 'everything was better' in the days of their youth. But I am sure that it is not this effect that explains my diagnosis. In my opinion, the explanation is basically as follows: the social status of physicists in Russia has changed. In the USSR, physicists and representatives of some other professions were so-to-say the salt of the earth. To be a physicist was prestigious. And, in addition, the salary of research workers was nearly the largest in the country, except that of higher party and Soviet functionaries. Now the conditions of science in Russia are very hard in any respect. There is not enough money for equipment and literature, and the salary is very low not only according to the international standards, but also compared to all types of clerks and secretaries in banks and firms even in Russia. At the same time, many rich people have appeared, sometimes simply rogues, who earn incomparably more than any first-class physicist. I do not think that our post-graduate students and candidates of science (approximately the Ph D level) live worse financially than they did in the 1950s, to say nothing of the 1930s and 1940s. But they are beggars compared to the so-called 'new Russians', all sorts of swindlers. This cannot but have its effect. But I am still not inclined to exaggerate and hope that Russia and, in particular, physics in Russia will raise their heads in the near future. However, the former students and colleagues of Efim Fradkin do not hang their heads even today and, in many respects, have adopted his anxious attitude and devotion to science. I believe that the present conference is one of the proofs of this. I hope the conference will be successful, and I wish you this success.

[3] It is this particular paper by F. Dyson that is mentioned in my paper [11] dedicated to the memory of D A Kirzhnits.

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E S Fradkin as a person

E L Feĭnberg

I would like to say a few words about Fradkin as a person. His scientific merits and achievements need not be specially described, suffice it to cast a glance at the audience and see how many actively working contemporary theoreticians accepted the invitation to attend this memorial conference.

As a person, he was remarkable in many respects. I shall dwell on only two of his outstanding features. He was a brave and clever man.

He was a courageous soldier and officer at the front during all the years of the Great Patriotic War, and this is confirmed not only by the number of awards he got, but also by another minute detail. Among the orders he received was the Order of the Red Star — not the highest award, but the one that had special significance. It was given for courage shown in the field of battle, face to face with the enemy.

But the usual everyday life in our country often required genuine courage from a man who wanted to remain honest. Fradkin joined the Communist Party at the front. At that time many people joined the party without sharing all its ideals or approving of all of its actions. This was simply the expression of hatred to nazism. The question may arise of why he stayed in the party many years after the war.

This question can only be asked by those who did not live in our country at that time and who do not understand that to withdraw was impossible, for it was fraught with serious penalties. I am aware of only one such case, but they were of course numerous.

In the dark period of persecutions which A D Sakharov was subjected to (as is well known, he worked in our Theoretical Department), the party bosses of our institute and higher ranked ones, from the District and even Central CPSU Committee, pounced upon Fradkin and other Party members of the Theoretical Department because they, as well as all other research workers of the department, refused to participate in the badgering and condemnation of Sakharov. The pressure of the party body was mainly concentrated on Fradkin. He was threatened with various punishments, and was not allowed to go to the Nobel scientific conference to which he had been invited as a speaker, but neither he, nor any of the Theoretical Department, including the other three party members, gave in. Fradkin, who was the head of the party group of the department, was thought of as being responsible for this.

In order to show how clever Fradkin was in ordinary life, I shall mention two episodes.

When Sakharov died, various rumors and politically colored versions concerning his death were spread. Fradkin realized that the situation had to be clarified. He went to the patriarch of Soviet autopsists Professor Rappoport, one of those physicians — 'killers in white smocks' who had been arrested several months before Stalin's death, and convinced him to come and participate in the post mortem examination to prevent any falsification. Rappoport was not an official member of the medical board charged with this mission by the government. But all the physicians involved were Rappoport's disciples and could not but allow him to take part in their work. And this put an end to all fantastic rumors.

The other example is not so gloomy.

When Fradkin was at the front, his commander once received an instruction: all soldiers who had a secondary education might hand in an application to enter the officer school. Almost all soldiers declared that they had a secondary education but had lost their documents in the chaos of the first war months. Fradkin's commander asked him whether he could quickly find out the truth. Fradkin said that he could, and that he only needed a room with two doors for the purpose. A soldier had to come in through one door and leave the room after the exam through the other door without having any contact with those waiting for their turn. The exam was organized as follows. A solder enters and Fradkin says to him: "Write: sin x". An illiterate soldier takes a pen and writes in Russian letters 'sinus iks'. Everything concerning his education becomes immediately clear.

Fradkin was a very attractive person. When he became a post-graduate student at our Department, I was already a professor. But the democratic spirit that reigned in the Theoretical Department was such that we became friends very soon.

In the last decades we lived in the same neighborhood and would often go for evening walks discussing various problems. His judgements were always clever and interesting. Those were happy hours. He was an honest, pleasant, and friendly man.

Efim Samoĭlovich Fradkin deserved fond memories of him.