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In memory of Efim Samoilovich Fradkin

Professor Efim Samoĭlovich Fradkin, full member of the Russian Academy of Sciences, an outstanding theoretical physicist, died after a severe illness on May 25, 1999.

E S Fradkin was born on November 30, 1924 in the settlement Shchedrin in Byelorussia, in a poor family with many children. When the war with Hitler's Germany began, Fradkin had completed one year at Minsk University. The Nazis exterminated almost the entire Fradkin family. Efim Samoilovich managed to escape from Minsk. From 1942 onwards, Fradkin fought at the front first as a private and then, after a severe wound obtained in the Battle of Stalingrad and after brief retraining, as an artillery officer. Still in the army in 1945, Fradkin attended courses at Lvov University. Having demobilized in 1946, Fradkin transferred to the day courses of the university. When graduating from the university in 1948, Fradkin wrote two graduation diploma projects, one of which was a generalization of V L Ginzburg's work for spin 3/2 to the case of spin 5/2. Lvov University professors refused to assess this paper and Fradkin, exercising the right of a veteran officer with war orders and medals, traveled to Moscow. Igor' Tamm and Vitaly Ginzburg immediately recognized his talent and insisted on his acceptance to a postgraduate position at the Theory Department of the P N Lebedev Physics Institute. In addition to purely theoretical work, Fradkin was busy doing calculations necessary for the hydrogen bomb project. In 1953 this work was awarded the USSR Stalin (State) Prize.

Fifty years of E S Fradkin's life were inseparable from the Theory Department of the P N Lebedev Physics Institute. He headed the section of quantum field theory and quantum statistics for more than 30 years.

E S Fradkin invariably gravitated towards hot topics of principal importance in elementary particle theory and quantum statistics.

Based upon Fradkin's work in the functional formulation of quantum field theory (QFT) and quantum statistics (both relativistic and non-relativistic), computational methods were elaborated that allowed a significant breakthrough beyond the scope of traditional perturbation theory. One of them was the superpropagator method known as the Fradkin-Efimov theory, which allowed theorists to work with essentially nonpolynomial perturbations. In relativistic quantum statistics, Fradkin derived a set of functional equations for the generating functional of Green's function and developed the corresponding diagram technique. In 1959 he showed that a Euclidean formulation of QFT emerges from these equations in the limit of zero temperatures and chemical potentials. Fradkin was the first to derive the completely renormalized set of equations for Green's function. Analysis of the highenergy regime of this set led him to discovering the conformal solution.

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Efim Samoĭlovich Fradkin (30.11.1924 – 25.05.1999)

A series of papers published by E S Fradkin on conformal quantum theory greatly contributed to the consolidation of this field. For example, he obtained the conformal formulation of the gauge theory, constructed a class of exactly solvable models in the *D*-dimensional case, created the complete classification of superconformal algebras, and developed a conformal gauge theory of higher spins. Conformal field theory always remained Efim Samoĭlovich Fradkin's favorite topic, and he continued to work on it until his last day; he planned to publish the second volume of his monograph *Conformal Field Theory in D dimensions*.

In 1955 E S Fradkin (simultaneously with L D Landau and I Ya Pomeranchuk) pointed to the inherent inconsistency in quantum electrodynamics. The fundamental importance of this phenomenon was later profoundly understood when the asymptotic freedom in the quantum theory of non-Abelian gauge fields was discovered. E S Fradkin was able to formulate the requirement of asymptotic freedom as the governing constraint for constructing models of grand unification. He was able to develop realistic asymptotically free models for unifying the strong, the weak and the electromagnetic interactions.

The derivation of the Ward-Fradkin-Takahashi identities in quantum electrodynamics was Fradkin's outstanding achievement. Generalized by Slavnov and Taylor to non-Abelian gauge theories, these identities are now a most important tool for studying the gauge theories. Fradkin derived these identities in quantum gravitation as well, and was the first to inject the idea of the asymptotic freedom of gravitational interaction at short distances.

Fradkin's contribution to the development of the quantum theory of gauge field is universally accepted. He carried out the canonical quantization in the Yang-Mills theory, proved the gauge independence of physical quantities and the renormalizability of the massive vector field in the gauge theory of weak interactions. E S Fradkin was the first to derive an accurate expression for the S-matrix of gravitation in arbitrary gauge. He was able to solve the problem of constructing the S-matrix for relativistic systems with constraints of the most general type. The Batalin-Fradkin-Vilkovisky formalism is a universal method, applicable to quantizing dynamic systems from the Yang-Mills gauge theory, (super)gravity and superstrings to conformal field theory models.

The quantum gravity, and string theory in particular, attracted vivid interest from Fradkin. The Fradkin – Tseytlin covariant sigma-model approach to describing the low-energy string dynamic, not burdened by expansion of the *S* matrix in number of fields, made it possible to clarify the general structure of the dilaton coupling constant dependence in the effective action of a string and led to the discovery of the crucial role of the Born – Infeld action of nonlinear electrodynamics in the quantum theory of open strings. These results are still at the center of attention in the current string theory.

Ever since his first paper on the Lagrangian formulation of a spin-5/2 free field, E S Fradkin retained an active interest in the theory of higher - spin fields. In the 1970s he constructed a model of N = 2 supergravity in the anti-de-Sitter space containing an electrically charged spin-3/2 field. This was the first example of a unified theory of gauge interactions based on supergravity and also a clarification of the fundamental role of anti-de-Sitter geometry in this theory. Later Fradkin and his students developed a theory of higher-spin gauge fields and found the infinite-dimensional symmetries of this theory.

In total, Fradkin published 250 papers and two monographs. A detailed bibliography of his publications prior to 1985 is given in *Quantum Field Theory and Quantum Statistics* (Essays in Honour of the sixtieth birthday of E.S. Fradkin) (Eds I A Batalin, C Isham, and G A Vilkovisky) Vols I and II (Bristol: Adam Hilger, 1987). It is indicative that 93 authors from 16 countries took park in this work.

We have mentioned those most significant results, which, in our opinion, give a fairly full, if not complete, impression of the great contribution to the development of theoretical physics made by E S Fradkin. His achievements received extensive recognition: he was given the military order of Red the Star, the civilian Red Banner and Sign of Honor, and a number of medals. In 1980 he won the I E Tamm Prize of the Academy of Sciences of the USSR, and in 1996 received the A D Sakharov Gold Medal of the Russian Academy. He was elected a foreign member of the Pontaniana Academy in Italy and received the Dirac Gold medal of the International Center of Theoretical Physics.

Efim Samoilovich trained a whole constellation of talented theoreticians, thus creating the Fradkin school. As a human being, he was an exemplary representative of the I E Tamm school. He actively supported A D Sakharov in the hard years of his exile to Gorkii. Efim Samoilovich's typical quality was that he approached the problems facing him with total devotion of effort and energy. People could only marvel at his ability to work hard, his energy and his scope of interests. He enjoyed the highest reputation among his physicist colleagues both in USSR and abroad and was always ready to discuss any (not only scientific) serious topic. To put it short, he was an intelligent and wise man.

E S Fradkin's death is a painful loss for all those who loved him and were in awe of him, and for the entire international community of theoretical physicists.

I A Batalin, M A Vasil'ev, G A Vilkovyskiĭ, V L Ginzburg, A V Gurevich, L V Keldysh, S E Konshteĭn, V I Ritus, I V Tyutin, V Ya Faĭnberg, E L Feĭnberg, A A Tseĭtlin