Problems of quantum field theory (based on the Proceedings of the Ninth International Symposium on Problems of Quantum Field Theory, Laboratory of Theoretical Physics, JINR, Dubna, 24–28 April 1990)

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The Ninth International Symposium on Problems of Quantum Field Theory took place from 24 through 28 April, 1990 at Dubna.

Symposia of this kind are traditional at the Joint Institute for Nuclear Research and have been organized by the directors of the Laboratory of Theoretical Physics for almost the entire time that this laboratory has existed. The first symposium took place in 1967, when field theory was regarded as by no means the most promising direction in the theory of elementary particles. Today, there can be no doubt about the topicality of the seminar subject matter.

The scientific program of the symposium was devoted to the most topical problems of modern field theory: new ideas in field theory; selected problems of quantum mechanics and field theory; supersymmetry and superstrings; QCD and quark models; nonperturbative methods of field theory; the standard model and its extensions; particle physics and cosmology.

The seminar was attended by 140 scientists from 14 countries. More than 90 papers were given, 15 of them being of a review nature.

In his welcoming words, the chairman of the organizing committee, Professor V. G. Kadyshevskiĭ, noted that quantum field theory contains an inexhaustible set of ideas that inspire ever new generations of physicists. He was confident that the symposium would play a positive part on the path to a deeper understanding of the fundamental laws of nature.

On the first day of the symposium papers were given in which *the most recent achievements in quantum field theory* were discussed. The main attention in this section was devoted to the development of the mathematical apparatus of field theory. V. S. Dotsenko (Institute of Theoretical Physics, USSR Academy of Sciences) reviewed the general structure of conformal field theories. Taking the example of a minimal (scalar) theory, he defined the basic elements, formulated problems, and showed that an effective method of solution is to represent the primary fields of the theory by free fields. Very recently, $SU(2)$ conformal theory was completely solved by this method, i.e., the correlation functions, operator algebras, anomalous dimensions, etc., for all the primary fields were found. There exists a hope that a representation by free fields can be constructed for any conformal theory, but at the present time a complete solution of $SU(N)$ extended theories with $N>2$ has not yet been found.

Another type of exactly solvable model was discussed by M. V. Savel'ev (Institute of High Energy Physics, Serpukhov), who reviewed infinite-dimensional Lie algebras of a new type—the so-called Z-graded algebras proposed by himself and A. M. Vershik in 1989. These algebras are a generalization of contragredient Lie algebras to the case of an infinite-dimensional Cartan subalgebra. The new algebras contain as a special case Kac–Moody algebras, Poisson-bracket algebras, Virasoro algebras, etc. By means of the Leznov–Savel'ev method, one can associate with these algebras a large class of integrable integro-differential nonlinear equations, including continuous analogs of the Toda chains.

P. P. Kulish (Leningrad Branch of the V. A. Steklov Mathematics Institute of the USSR Academy of Sciences) discussed the comparatively recently developed concepts of quantum Lie algebras and groups. These new mathematical objects, which in many respects are analogous to the ordinary algebras, arise in the quantum inverse scattering method and in the Yang–Baxter equations. Quantum Lie algebras depend on a parameter q and are identical to the ordinary algebras in the limit $q\rightarrow 1$. They appear in the context of standard problems of theoretical physics such as the description of the symmetry of a given Hamiltonian (in this case, q depends on the coupling constant), the properties of rational conformal theory, and the hidden symmetry of the quantum theory of the Liouville equation, for which the parameter characterizes the representations of the minimal model.

The paper of Professor J. Zinn-Justin on two-dimensional quantum gravity stimulated great interest. He discussed the progress recently achieved in the construction, by the method of random matrices, of an exact solution in the model of two-dimensional gravity interacting with matter fields of dimension $d<2$. This problem, the simplest form of quantum gravity, is close to investigations of string field theory and statistical physics. In many cases, the matrix problem can be solved by an appropriate choice of orthogonal polynomials. One can show that in the continuous limit the method of orthogonal polynomials is equivalent to the construction of a representation of the canonical commutation relations in terms of differential operators. In the case of pure gravity, the sum over the topologies reduces to the solution of nonlinear differential equations and agrees with the results obtained earlier by Knizhnik, Polyakov, and Zamolodchikov. The case $d=1$

can also be treated semiclassically and corresponds to the quantum mechanics of $N \times N$ Hermitian matrices. Unfortunately, it has not yet been possible to extend this analysis to the case $d > 1$.

Quantization of gauge theories corresponds to study of dynamical systems subject to constraint conditions. These problems have a long history, and their solution is of fundamental importance for the construction of realistic field theories. Professor A. A. Slavnov (V. A. Steklov Mathematics Institute, USSR Academy of Sciences) reported on a new effective method of quantization in an extended phase space that makes it possible to overcome many difficulties inherent in the standard method.

Another new direction based on study of the topological properties of field theory was presented in the paper of Professor C. Fronsdal (University of Los Angeles, USA). Together with M. Flato he formulated a gauge theory (with indefinite metric) of a scalar field. The basic objects of the theory are topological field excitations—singletons. Such solutions arise in three-dimensional QED, and can also appear in the role of constituent massless particles in four-dimensional theory. Singleton theories are finite in the infrared region and possess confinement properties. Therefore, they can be used in models of the strong interactions.

Besides the successes in finding exact solutions in field theory, much attention was devoted at the symposium to perturbation methods. The papers of F. V. Tkachev, A. L. Kataev, V. V. Vlasov, and A. A. Pivovarov, who work at the Institute of Nuclear Research of the USSR Academy of Sciences, gave a review of new results in the theory and applications of multiloop calculations. The theory of generalized functions provides an adequate basis for the investigation of multiloop diagrams. On its basis, one can define the concepts of the renormalization-group operation, ultraviolet and infrared divergences, operator expansion, and more. The R^* operation, which is a powerful tool for renormalization-group calculations, has been constructed, and a new representation has been obtained for the ultraviolet R operation. The formalism that has been developed is valid not only for justifying the operator expansion and for detailed study of Euclidean asymptotic expansions but also for practical calculations made in QCD and supersymmetric, scalar, and other models.

Professor O. I. Zav'yalov (V. A. Steklov Mathematics Institute, USSR Academy of Sciences) is a great expert on the development and applications of the R operation in gauge theories, including QCD, and the author of well--known monographs devoted to these questions. His paper at the conference devoted to various aspects of the method of regularization stimulated lively interest of the participants.

D. I. Kazakov (JINR) presented a general approach to the construction of models of quantum field theory free of ultraviolet divergences. He showed that the conditions for a theory to be finite have a single-loop nature. He formulated a criterion for finiteness and considered a number of interesting examples in dimensions $D = 2$ and $D = 4$.

Selected problems of quantum mechanics and field theory were reflected in the reports of B. A. Arbuzov (Institute of High Energy Physics, Serpukhov), D. A. Slavnov (Moscow State University), G. V. Efimov (JINR), R. M. Mir-Kasimov (JINR), A. Della Selva (Naples, Italy), L. G. Zastavenko (JINR), N. Ilieva (JINR), A. M. Malokostov (V. A. Steklov Mathematics Institute, USSR Academy of Sciences), S. V. Shabanov (JINR), A. P. Demichev (Moscow State University), S. V. Zenkin (Institute of Nuclear Research, USSR Academy of Sciences), and others.

A. B. Govorkov (JINR) showed that in local quantum field theory violation of the Pauli principle is in principle impossible. He proposed a new scheme of generalized quantization of fields corresponding to parastatistics of identical particles. Problems of statistics were also discussed by V. A. Strazhev (Institute of Physics, Belorussian Academy of Sciences).

G. P. Korchemskiĭ (JINR) revealed the origin of the parity anomalies in the $D = 3$ Chern–Simons gauge theory. The anomalous contribution, when added to the classical action, leads to an additive integral renormalization of the coupling constant. This confirms the suggestion made earlier by Witten.

New results of investigations into the behavior of field theory at finite temperatures and pressures were presented in the papers of A. I. Bochkarev, D. A. Grigor'ev (Institute of Nuclear Research, USSR Academy of Sciences), O. A. Borisenko (Institute of Theoretical Physics, Ukrainian Academy of Sciences), and E. Ferrer (Cuba).

The theory of gravitation without nonlocalizable objects was discussed by N. A. Chernikov (JINR). Problems of the theory of gravitation were also discussed in the papers of N. S. Shavokhina (JINR) and M. N. Tentyukov (JINR).

At the symposium, much time was devoted to problems of *supersymmetry and superstrings*. In a review of string field theory, I. Ya. Aref'eva (V. A. Steklov Mathematics Institute, USSR Academy of Sciences) showed that the theory of open strings and superstrings can largely be regarded as constructed. The existing results agree with the known results of the Veneziano–Koba–Nielsen model. However, the theory of closed strings contains many unresolved problems and requires further development.

A review of supersymmetric σ models was presented by A. S. Gal'perin (JINR). Problems of symmetry breaking, the description of supersymmetric particles, and the quantization of supersymmetric and superstring theories were considered by J. Lukierski (Poland), A. A. Zheltukhin, D. P. Sorokin (Khar'kov Physicotechnical Institute, USSR), M. S. Plyushchai (Institute of High Energy Physics, Serpukhov), V. V. Nesterenko, A. P. Isaev, A. M. Chervyakov (JINR), B. M. Zupnik (Tashkent State University), and A. Yu. Khrennikov (V. A. Steklov Mathematics Institute, USSR Academy of Sciences).

Many papers presented at the symposium were devoted to various applications of *QCD and quark models* in the theory of elementary particles. The results directly related to the use of QCD in the theory of strong interactions were presented in a review paper by A. V. Radyushkin (JINR). Recently, an improvement of the method of QCD sum rules, which effectively takes into account large-distance effects, has significantly extended its region of applicability. In particular, the recently calculated hadronic part of the photon structure function predicts a behavior very different from the estimates obtained in the vector--dominance model. For further development of the method it is, in particular, necessary to develop a more detailed picture of the QCD vacuum, and also to clarify the reason for the appearance of large perturbative corrections in the power-law contributions.

The behavior of the hadron form factors is still outside the ambit of perturbation-theory methods. M. Chaichian and M. A. Tornqvist (University of Helsinki, Finland) proposed a phenomenological model in which, in contrast to the power-law behavior predicted by asymptotic QCD, the form factors have exponential behavior. In such a model, one can describe the decay of Ψ and Ψ', and even the φ particles.

At the same time, agreement between theory and experiment is undoubtedly observed in the perturbative region. V. T. Kim (Leningrad Institute of Nuclear Physics) presented a scheme-invariant analysis of the latest SDHSW data on the structure functions of deep inelastic scattering; this analysis makes it possible to reduce considerably the error in the determination of the parameter $\Lambda_{\overline{\rm MS}} = 270 \pm 50$ MeV. This value agrees with results obtained earlier from $e\mu$ data.

In their paper, M. K. Volkov and D. Ebert (JINR) gave a detailed discussion of the connection between QCD, as the field theory of strong interactions, and chiral Lagrangians, as the effective low-energy theory of QCD. In these models, the pseudoscalar mesons can be introduced in two different ways: as the chiral phase of the quark field or as composite quark–antiquark states. As a result, the effective model of the strong interactions at low energies can be represented as a linear or nonlinear σ model. In the latter case Skyrmion solutions, which make it possible to describe baryons, arise. Various aspects of this approach and its numerous applications were considered in the papers of G. Ecker (University of Vienna, Austria), A. A. Andrianov (Leningrad State University), U.-G. Meissner (University of Bern, Switzerland), V. A. Nikolaev (JINR), V. Yu. Novozhilov (Leningrad State University), and E. P. Shabalin (Institute of Theoretical and Experimental Physics, USSR).

M. A. Ivanov (JINR) proposed a quark–diquark approximation for the three-quark structure of baryons. In the framework of these ideas, the basic properties of baryon physics have been calculated.

The interest of the participants was stimulated by the discussion of the papers on problems of bound states in QCD [V. N. Pervushin (JINR), R. N. Faustov (USSR Academy of Sciences), N. A. Sarikov (Tashkent State University), and L. Kashlun (JINR)], meson physics [N. N. Achasov (Institute of Mathematics, Siberian Branch, USSR Academy of Sciences), M. A. Tornqvist, and V. I. Sabov (Uzhgorod State University)], and hadron processes [M. V. Margvelashvili (Tbilisi State University) and É. A. Kuraev (Institute of Nuclear Physics, USSR Academy of Sciences)].

Many papers were devoted to spin physics. They were stimulated by the recent EMC experimental results on the spin structure of the proton, which do not fit in the framework of the standard ideas of the naive quark model ("spin crisis"). A. V. Efremov (JINR) showed that the crisis situation can be eliminated by taking into account the axial anomaly, by virtue of which there arises an additional contribution to the proton spin, which compensates the contribution of the valence quarks. This subject was also discussed by A. V. Kiselev, A. P. Samokhin, and V. A. Petrov (Institute of High Energy Physics, Serpukhov), O. V. Teryaev (Dnepropetrovsk University, USSR), A. E. Dorokhov (JINR), F. S. Sadykhov (Baku, USSR), and others.

In his review paper, J. Soffer (Saclay, France) emphasized that the study of polarization processes is important for clarification of some intrinsic features of strong interactions and hadron structure. The importance of spin phenomena for testing the standard model at low energies was also noted by S. B. Gerasimov, S. V. Goloskokov (JINR), M. P. Chavleĭshvili (Tbilisi State University), and V. E. Troitskiĭ (Moscow State University).

Proposals for experiments at the currently planned c–τ factories were presented by N. N. Achasov and A. A. Kozhevnikov (Institute of Mathematics, Siberian Branch, USSR Academy of Sciences), M. K. Volkov, and A. A. Osipov (JINR). Problems of new physics at the most recently completed facilities were discussed by D. Dominici (Genoa, Italy), I. F. Ginzburg (Institute of Mathematics, Siberian Branch, USSR Academy of Sciences), and F. Csikor (Hungary).

The next interesting section of the seminar was devoted to *nonperturbative methods in field theory*. M. I. Polikarpov (Institute of Theoretical and Experimental Physics, USSR) reviewed the confinement problem in lattice theories. Calculations on a lattice are an alternative and more direct approach to the study of strong interactions. It is found that the confinement mechanism due to condensation of monopoles that form a superconducting phase corresponds to the appearance of monopole currents of nonintegral dimension. There are weighty arguments for supposing that the formation of a string between quarks is analogous to the formation of an Abrikosov filament in a superconductor.

V. K. Mitryushkin (JINR) reported lattice study of the dependence of the internal energy on a constant external chromomagnetic field. The topological structure of the vacuum in lattice theories was the subject of the paper of M. Mueller-Preussker (Berlin, German Democratic Republic).

Intermittence and fractal ideas, and also theoretical models that explain the dynamics responsible for fluctuations were presented by I. M. Dremin (P. N. Lebedev Physics Institute, USSR Academy of Sciences). He reviewed experimental results on fluctuations of the particle number in small rapidity intervals in inelastic processes.

Review papers of D. Yu. Bardin and M. E. Shaposhnikov were devoted to the *standard model* of electroweak interactions. In his review, very rich in content, Bardin

(JINR) discussed in detail the results recently obtained at LEP. He showed that the experimental data are in excellent agreement with the predictions of the standard model with the number of light generations equal to 3. In the investigated range of energies, there are no signs of new physics. Higgs particles lighter than 24 GeV are ruled out.

Through the LEP experiments, most parameters of the standard model have been measured with a high degree of accuracy. However, the masses of the Higgs boson and of the t quark remain unknown. M. E. Shaposhnikov (Institute of Nuclear Research, USSR Academy of Sciences) gave the latest theoretical bounds on these masses. Besides the known experimental bounds, a narrow region of possible mass values is allowed: $m_H = 24$–45 GeV, $m_t = 80$–120 GeV. Thus, if these predictions are not confirmed, new ideas concerning the mechanism of spontaneous symmetry breaking, doubling of the generations, etc., will be necessary.

The solution of existing *cosmological problems* may also make it necessary to go beyond the framework of the usual ideas. A brief review of the present state of the cosmology of the early universe was given by A. D. Dolgov (Institute of Theoretical and Experimental Physics, USSR). He characterized the unresolved cosmological problems and noted the need for new physics going beyond the framework of the standard $SU(3)\times SU(2)\times U(1)$ model. A central position in these unresolved problems is that of the cosmological constant, for which the theoretical estimates differ from the observed values by 50–100 orders of magnitude.

The number of papers read at the symposium significantly exceeded the number characteristic of the earlier symposia of the series. This is evidence of the popularity of such symposia and the large interest in them. They make it possible for Soviet theoreticians to meet their colleagues from abroad, provide a basis for the start of joint investigations, and help to draw young talented researchers into theoretical physics. "Scientists need lively direct contacts because no computer network and no telefax can replace personal encounters" — these expressive words of Professor C. Fronsdal are the best possible characterization of the atmosphere at the symposium. The participants were of the unanimous opinion that such symposia should be held regularly.

In this brief report not all papers have been mentioned, and not all subjects have been represented with the necessary completeness. We hope that this gap will be filled by the Proceedings of the Ninth International Symposium on Problems of Quantum Field Theory, which will contain the review and invited papers and are currently being prepared for publication by the organizing committee.

Translated by Julian B. Barbour