The present status of quantum field theory (from materials of the Sixth International Conference on Problems of Quantum Field Theory. Alushta, Crimea, May 5–9, 1981)

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The Sixth International Conference on Problems of Quantum Field Theory was held on May 5–9, 1981 at Alushta.

This conference, like the five preceding it (Dubna 1967; Azau, 1970; Alushta, 1973, 1976, 1979), was organized on the initiative of the Directors of the Theoretical Physics Laboratory of the Joint Institute of Nuclear Research.

One hundred and ten scientists from eight countries participated in the work of the conference. They heard and discussed 45 papers, 11 of which were of the nature of reviews.

The conference discussed the most urgent problems of contemporary field theory:

- –Rigorous results in quantum field theory and in quantum statistics.
- –Exactly solvable models in classical and quantum field theory.
- –Gauge theories.
- –Quantum chromodynamics.
- –Chiral theories and bags.
- –Unified theories.
- –Supersymmetry and gravitation.

The conference showed that the subject matter selected reflects most fully the principal trends of research in quantum field theory. Significant progress had been made during the past two years in each of the above areas.

1. RIGOROUS RESULTS IN QUANTUM FIELD THEORY AND IN QUANTUM STATISTICS

A review paper by N. N. Bogolyubov, Jr. (Steklov Institute of Mathematics of the USSR Academy of Sciences, MIAN) and V. N. Plechko (Joint Institute of Nuclear Research, JINR) examined new variational methods of approximation in the theory of electron-phonon systems that are based on elimination of the phonon variables by the method of chronological products. Approximating expressions have been obtained for the equilibrium free energy and time correlation functions. It is significant that the proposed approach is applicable in the ranges of both weak and strong coupling.

A communication from A. N. Kurbatov and D. P. Sankovich (MIAN) entitled "Clusterization of the Hamiltonian and the Bogolyubov (Jr.)–Petrina Theorem" established the possibility of broadening the class of model Hamiltonians for which the correlation functions for the initial Hamiltonian are solutions of the same equations that the correlation functions for the approximating Hamiltonian satisfy. For a translationally invariant Hamiltonian describing a system in which only particles from a few defined groups (clusters) interact, they present a constructive derivation of an approximating Hamiltonian that is thermodynamically equivalent to the initial Hamiltonian.

A communication from A. A. Logunov, B. V. Medvedev, L. M. Muzafarov, V. P. Pavlov, M. K. Polivanov and A. D. Sukhanov (MIAN) was devoted to the analytic structure of the amplitude of $3 \to 3$ forward scattering (generalized optical theorem) within the framework of Bogolyubov's asymptotic approach.

The problem of mathematically correct definition of functional integrals in quantum theory was discussed in a communication from P. Exner and G. I. Kolerov (JINR): "Description of the Dynamics of Nonclosed Systems with the Aid of Strictly Defined Feynman Integrals," It was shown that the dynamics of nonclosed quantum-systems with a complex time-dependent potential can be described by a formula of the Feynman-Ito type. An explicit expression was obtained for the propagator of a d-dimensional damped oscillator which, on the disappearance of damping, gives the correct Maslov phase multiplier.

A communication from V. N. Popov (Leningrad Branch of Steklov Institute of Mathematics, LOMI) on "Two-Dimensional Field Theory with Several Condensed Phases" reported the results of an effective-action study of field models with four-fermion current-current interaction. A phase transition from a symmetric to an asymmetric phase was observed in the two-dimensional theory. Different numbers of Goldstone Bose-excitation modes exist in the different phases, in an analogy to the superfluid phases of He^3.

A communication from V. A. Il'in, M. S. Imashev, and D. A. Slavnov (Moscow State University, MGU) proposed a new renormalization variant. It was shown that a renormalized Feynman diagram with N loops can be represented in the form of a special convolution of the $(N-1)$-th Feynman diagram with the propagator of the free field. This makes it possible to formulate a loop-renormalization scheme that is independent of the R operation. It is demonstrated that the proposed renormalization scheme is equivalent in its final result to the R operation.

A communication from Yu. M. Lomsadze (North Ossetian University) was devoted to a new version of the Bogolyubov and Wightman axiomatic approaches in the quantum theory of local and nonlocal fields.

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An interesting relation of the mathematical formalism of the renormalization group to a nonlinear problem of radiation transfer was set forth in a report from M. A. Mnatsakanyan (Byurakan Astrophysical Observatory of the Academy of Sciences of the Armenian SSR).

2. EXACTLY SOLVABLE MODELS IN CLASSICAL AND QUANTUM FIELD THEORY

L. D. Faddeev (LOMI) reviewed the development of the quantum method in the inverse scattering problem over the two years since the preceding Alushta conference. The following important results have been obtained in this area. An exact formulation of the lattice approximations was given for integrable models. Trace formulas have been derived for the local quantum conservation laws. The S-matrix has been constructed for the excitations. A derivation of a quantum analog of the Gel'fand-Levitan-Marchenko equation has been given. The paper discussed prospects of the method and took note of unsolved problems.

A geometric concept that has been used successfully in recent years in the mathematical apparatus of elementary-particle physics is that of the minimal surface (relativistic-string model, Wilson criterion for retention of quarks in hadrons). For the first time in relativistic physics, minimal surfaces appeared in a study of Born-Infeld nonlinear field models. A review by N. A. Chernikov and N. S. Shavokhina (JINR) discussed the use of minimal-surface theory in nonlinear electrodynamics and in the relativistic two-body problem. A system of covariant equations was obtained for a nonlinear electrodynamics of the Born-Infeld type in an n-dimensional Riemann universe. It was shown that plane traveling waves are solutions of the equations of both linear and nonlinear electrodynamics in an n-dimensional Poincare-Minkowski universe. Solutions of the electrodynamic equations have been obtained (in both the linear and nonlinear cases) in the n-dimensional Poincare-Minkowski universe in the form of two-dimensional surfaces in the n-dimensional universe. The problem of collision of two traveling plane waves was discussed. It was noted that minimal-surface equations appear in nonlinear field theory. The minimal surface in the Poincare-Minkowski universe also appears in the relativistic two-body problem and permits relativization of the Newton equations for two bodies when the interaction potential is proportional to the distance between them.

A paper by B. M. Barbashov, V. V. Nesterenko and A. M. Chervyakov (JINR) was devoted to the use of the methods of classical differential geometry to obtain general solutions of a whole class of nonlinear second-order partial differential equations with two independent variables. These equations determine the basic differential forms of a two-dimensional minimal surface embedded in n-dimensional pseudoeuclidean space. The relation of the proposed approach to the group methods for solution of nonlinear equations was discussed.

Special transformations of nonlinear evolutionary equations that are integrable by the inverse scattering problem method were discussed in a communication from V. K. Mel'nikov (JINR). The author found two classes of nonlinear evolutionary equations that are related to one another by transformations similar to the Miura transformation. The relation between the symmetries of these equations was investigated.

A report from V. S. Gerdzhikov (JINR) and P. P. Kulish (LOMI) was devoted to a quantum variant of the nonlinear Schrödinger equation. It was shown that the quantum inverse scattering problem method can be used to solve this equation. The energy spectrum was obtained and the Bethe ansatz was used to construct the exact quantum states.

V. G. Makhan'kov (JINR) reported results from a study of the nonlinear Schrödinger equation in two-dimensional space-time with a non-compact group of internal symmetry $U(p, q)$, $p+q=n$.

3. GAUGE THEORIES

The conference devoted much attention to general problems in the theory of nonabelian gauge fields. A review of new results obtained in this area outside of the framework of coupling constant perturbation theory was presented by A. A. Slavnov (MIAN). He discussed the phenomenological status of the color-number expansion in quantum chromodynamics and, specifically, equations for the Wilson functional as $N_c \to \infty$ and equations for the Green's functions in SU(2) theory in terms of colorless bilocal variables. A new approach to investigation of the infrared behavior of nonabelian gauge theories was proposed in a paper by B. A. Arbuzov (Institute if High Energy Physics, IFVÉ). The infrared behavior of the quark propagator in QCD was investigated with the aid of asymptotic solutions of the Schwinger-Dyson equations. It was shown that a solution with a pole may exist at perferred values of the quark masses. An application of this method to massive vector theories, where a physically acceptable solution can be obtained at preferred coupling-constant values, was given.

The problem of transition to the continuum limit in a field theory defined on a lattice was discussed in a paper by M. Marinaro (Italy). A Euclidean N-component $g\Phi^4$ theory on a lattice was studied. It was shown that the transition to the continuum limit is trivial for small g. For large g, a correct result can be obtained only if the analytic continuation of the corresponding Padé approximations is made first, followed by transition to the continuum limit.

Inclusion of instanton solutions in the Yang-Mills theory was discussed in a communication from É. M. Il'genfrits, D. I. Kazakov, and M. Myuller-Proisker (JINR). The leading instanton contributions to charge renormalization were found by calculating two- and three-point Green's functions in the dilute instanton gas approximation. The resulting β function experiences rapid growth in the region of $g=1$, in good agreement with extrapolation of the result obtained in Euclidean theory on a lattice in the strong-coupling regime. A. K. Kwasznewski (Poland) reported a study of Gaussian fluctuations about single-instanton solutions in

an HP(1) σ model describing composite SU(2) gauge fields.

A communication from Yu. N. Kafiev (Mathematics Institute, Siberian Division, USSR Academy of Sciences) on "Four-Dimensional Sigma Models and Composite Yang-Mills Fields" presented an SU(2) gauge-invariant sigma model on HP^n quaternion projective space. The model is topologically nontrivial for arbitrary n and has instanton solutions. A relation of the HP^1 model to the O(5) model of Skyrme was indicated. Feynman rules were derived for an arbitrary O(N) Skyrme model by reducing the Lagrangian of this model to the Lagrangian of a massive Yang-Mills field interacting with an ordinary sigma model in the infinite-mass limit.

A communication from R. Kischner (GDR) reported results on the summation of doubly logarithmic contributions to the quark-quark scattering amplitude and to the amplitude of annihilation in all orders of perturbation theory in quantum chromodynamics. The possibility of generalizing the results obtained by Gorshkov *et al.* in quantum electrodynamics to the case of the nonabelian theory was discussed.

4. QUANTUM CHROMODYNAMICS

The papers devoted to quantum chromodynamics (QCD) formed one of the centers of attention at the conference. The development of this theory has permitted a direct approach to its verification in the experimentally accessible energy range.

A paper by A. V. Efremov and A. V. Radyushkin (JINR) presented a detailed review of studies devoted to an analysis of the radiative (i.e., multiloop) and power-law corrections to the amplitude and cross section of hard processes in quantum chromodynamics, Attention was concentrated on those studies that have made it possible to improve the accuracy of QCD predictions. The dependence of the final calculated results on the chosen QCD renormalization scheme was discussed in this context, as was the problem of determining the fundamental scale in this theory.

At this time, exotic quark states present a high-priority problem from the standpoints of both theory and experiment. V. I. Zakharov (Institute of Theoretical and Experimental Physics, ITÉF) discussed this problem within the framework of quantum chromodynamics. He reviewed the predictions of various models for the exotic states (including among the latter both multiquark mesons and gluons). The bag model, large N_c and sum rules for quantum chromodynamics were discussed. It was shown that different schemes lead to different predictions. The disagreements are especialy wide in applications of these models to gluon physics.

A most important property of quantum chromodynamics is its asymptotic freedom, i.e., a decrease in the effective constant of interaction of quarks with gluons with increasing energy. It is precisely by virtue of this property that QCD claims to describe strong interactions. However, the influence of asymptotic freedom in QCD was obtained only with the aid of perturbation-theory calculations. It is therefore extremely important to investigate this problem without using iterative series. This problem was discussed in such a formulation in a communication from Z. Khaby (Poland). The manifested stability properties of QCD in a strong background field may be regarded as a base for asymptotic freedom in this theory. A communication from P. S. Isaev (JINR) was devoted to approximate solution of the evolutionary equations of quantum chromodynamics. Distribution functions for quarks and gluons in the nucleon that satisfy the system of integro-differential evolutionary equations of quantum chromodyanmics (the Altarelli-Parisi equations) with high accuracy were presented in explicit analytic form.

Several results have recently been obtained by formulating quantum chromodynamics in the language of Wilson functionals specified on contours. The problems of renormalization of the corresponding functional equations and their singular behavior at short distances were discussed as they arise here in communications from F. Kashlun (GDR) and E. Witsorek (GDR).

A paper by L. N. Lipatov (Leningrad Institute of Nuclear Physics, LiYaF) was devoted to the physical properties of the Pomeranchuk singularity in quantum chromodynamics. The equations for t-channel partial waves were solved for various dimensions of space-time ($D = 2, 3$). A generalization was proposed for the principal logarithmic approximation, namely a procedure for construction of amplitudes with multi-Reggeon unitarity. Such an amplitude was found in explicit form in the model case of elastic unitarity.

Quark-bag models currently form a phenomenological hadron model. Clarifying the relation of this approach to quantum chromodynamics is of unquestionable interest. Developing the analogy between gluon fields and the quantum liquid, V. N. Pervushin (JINR) arrived at a hypothesis of dominance in strong interacting self-dual fields in Minkowski space. He showed that the theory of spinor particles in such nonabelian fields is a relativistic variant of the hadron-bag model.

What potential describes the interaction between quarks and hadrons, and how can it be obtained within the framework of quantum chromodynamics? These questions are no doubt of extreme importance from the standpoint of comparing the predictions of quantum chromodynamics with experimental data (hadron spectroscopy, hadron decays). They were discussed in detail in a communication from M. V. Terent'ev (ITÉF), in which he proposed derivation of a multipolar expansion for the energy of interaction of a pair of quarks in a longwave vacuum fluctuation field within the framework of quantum chromodynamics. F. S. Sadykhov (Azerbaĭdzhan University) spoke on specific calculations with the aid of a quark-parton model of the hadrons.

5. CHIRAL THEORIES AND BAGS

One important problem in contemporary elementary particle physics is that of establishing relations between

quantum chromodynamics, the predictions of which pertain to high-energy processes, and the chiral theories, which accurately describe strong interactions at low energies. Several papers presented at the conference were devoted to this problem.

P. di Vecchia (Italy) presented a paper on "Chiral Dynamics in Quantum Chromodynamics," proposing an effective Lagrangian that describes the low-energy dynamics of pseudoscalar mesons in quantum chromodynamics with large N_c.

M.K. Volkov (JINR) reported the results of calculations of $\eta \to 3\pi$ and $\eta \to \pi^0\gamma\gamma$ decays in $U(3)\times U(3)$ chiral theory. The value obtained for the width of the $\eta \to \pi^0\gamma\gamma$ decay was $1.3 \cdot 10^{-3}$ eV, which differs by 4 orders of magnitude from the old experimental data. Preliminary results obtained recently at the IFVÉ (Protvino) do not contradict these theoretical predictions.

A communication from M.M. Musakhanov (Tashkent State University) on "A Chiral Bag Model" proposed unification of the quark-bag model with the nonlinear sigma model.

A review of low-energy hadron interactions in a nonlocal quark model was presented in a paper by (M. Dineĭkhan, G.V. Efimov, and M.A. Ivanov) (JINR). This approach is a self-consistent quantum-field model of the relativistic bag. Rare decays of pseudoscalar and vector mesons were calculated, and the results were found to agree closely with recent experimental data. It was found that available experimental data are consistent with the hypothesis that scalar mesons form a two-quark system.

6. UNIFIED THEORIES

Unified theories of weak, electromagnetic, and strong interactions were discussed with lively interest at the conference. A paper by A. Yu. Ignat'ev, V.A. Kuz'min, V.A. Matveev, and M.E. Shaposhnikov (USSR Academy of Sciences Institute of Nuclear Research, IYaI) reviewed theories of the great unification and their experimental and cosmological implications. The following problems were considered: proton decay, neutron-antineutron oscillations, and the baryonic asymmetry of the Universe. In conclusion the problems of and prospects for the great unification were discussed from the standpoint of elementary particle physics and cosmology.

A. Yu. Ignat'ev, V.A. Kuz'min, and M.E. Shaposhnikov (IYaI) discussed the problems of the baryonic asymmetry of the Universe in detail within the framework of a specific great unification model, namely in $(SU(4))^4$ minimal theory. It was shown that spontaneous violation of B symmetry, which occurs in this theory along with violation of color symmetry at energies ~1 GeV, is not consistent with cosmological data.

A supersymmetric model of electromagnetic, weak, and strong interactions with the symmetry group $SU_L(2)\times SU_R(2)\times SU(4)$ was presented in a communication by G.M. Vereshkov, V.A. Dubrovskiĭ, and V.A. Savchenko (Rostov University). They discussed the consistency of this model with existing experimental data and took note of those predictions of the theory verification of which would become possible in the energy range 10^2–10^3 GeV in the center-of-inertia system. The physical processes experimental investigation of which is of interest from the standpoint of verification of the supersymmetry hypothesis were enumerated.

A paper by V.I. Sabov, E.S. Grdlichka, and M.V. Solodzhuk (Uzhgorod University) was devoted to calculation of specific processes on the basis of an eight-quark vectorlike model of weak and electromagnetic interactions.

7. SUPERSYMMETRY AND GRAVITATION

The theory of supergravitation is now one of the most promising trends in elementary-particle physics. The papers on this subject that were presented at the conference indicated significant progress in development of an effective mathematical apparatus for this theory. A review paper by V.I. Ogievetskiĭ (JINR) was devoted to development of a dynamic approach to supergravitation that he had proposed earlier. This approach is unique in that it is the only one in which all implications of the theory proceed from the principle of action and from geometry. The productivity of the Grassman analyticity, concept was demonstrated. The decisive importance of the central and semicentral charges (especially in expanded supergravitations) was emphasized.

The problem of describing the interaction of Einstein fields with gauge fields was discussed in a report by D.V. Volkov and V.I. Tkach (Khar'kov Physicotechnical Institute). The solutions that the authors found for the equations that describe such interactions indicate the possibility of compactification of the subspaces into symmetric spaces.

A report from J. Inderle (Chechoslovakia) and E.A. Ivanov (JINR) presented a gauge formulation from a unified point of view of various gravitational theories (Einstein, Einstein-Cartan, Weyl, and others). The complete invariance group of the Lagrangian has the form $H^{loc}\otimes \mathrm{Diff}\, R^4$. Here Diff R^4 is a general covariant group that operates on the coordinates x_μ, and H^{loc} is a local gauge group that appears on localization of the global symmetry group H. The group H^{loc} operates in a tangential space associated with each point x_μ. Different H groups correspond to different theories of gravitation. The group H^{loc} must be spontaneously violated to eliminate the extra gauge fields.

The properties of the gravitational vacuum and their relation to physical interactions were discussed in a communication from V.N. Mel'nikov (All-Union Scientific Research Institute of Physicotechnical and Radiotechnical Measurements).

The papers devoted to certain specific problems of elementary-particle physics were received with great interest by the conference.

Original ideas for application of geometry to quantum

mechanics were advanced in a paper by E. R. Caianiello (Italy) on "A Game with Geometry and Quantum Mechanics." It is noteworthy that this approach can be regarded as an alternative to the usual attempts to quantize the general theory of relativity.

A review paper by S. M. Belen'kiĭ and F. Niedermayer (JINR) was devoted to the problem of neutrino oscillations. Various neutrino-mixing schemes were examined in detail. The problem of *CP* violation in the lepton sector was discussed, and a possible experiment in search of *CP* violation in the oscillation was proposed. The results of the most recent experiments in search of neutrino oscillations were reviewed.

The participants who spoke at the closing session [L. D. Faddeev (USSR), E. R. Caianiello (Italy), and F. Kashlun (GDR)] gave the conference high marks. The great importance of such meetings between physicists for productive exchange of ideas in quantum field theory and the unquestionable value of repeating them periodically were noted. The publications section of the JINR has published a collection of the papers presented at the Sixth International Conference on Problems of Quantum Field Theory, which contains primarily the review papers.

Translated by R. W. Bowers