Fundamental problems of quantum field theory (from materials of the Fourth International Meeting on Non-Local Quantum Field Theory, Alushta, April 21–27, 1976)

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In recent years there has been a striking growth of interest among elementary-particle physicists in the methods and ideas of quantum field theory. After the vigorous development of quantum field theory which took place in the 1950s and the subsequent waning of interest in the subject, we are now witnessing a period of new enthusiasm. New and highly promising aspects of field theory are being studied, and old problems are being solved at a totally new mathematical level. These efforts are already capable of yielding interesting physical consequences in the field-theoretic approach and offer hope of even greater discoveries in this area in the near future.

In this situation it is of great importance to organize international conferences and meetings to review the status of quantum field theory and to assess the prospects for its future development. The Fourth International Meeting of Non-Local Quantum Field Theory was one such meeting, whose purpose was to review the progress in field theory during the three years that have elapsed since the Third Meeting (Alushta, 1973).[1]

The six working days of the meeting were devoted to six of the most pressing problems of quantum field theory:

1) non-local quantum field theories;
2) chiral theories and gravitation;
3) gauge and supersymmetric theories;
4) particle-like solutions in field theory (solitons);
5) dual resonance models and relativistic string models;
6) quark models of extended particles.

It was pointed out in a report by D. I. Blokhintsev that all these themes of the meeting were unified by three basic ideas: 1) the study of non-local theories from various points of view; 2) the increasingly important role of dynamical symmetries in field theory; 3) the abandonment of ordinary perturbation theory (essentially non-linear fields).

One of the basic difficulties of quantum field theory is the problem of eliminating ultraviolet divergences. Methods of solving this problem within the framework of non-local quantum field theory were reviewed in reports by G. V. Efimov and by V. G. Kadyshevskiĭ *et al.* G. V. Efimov was able to construct non-local quantum field theories, both for scalar fields and for spinor electrodynamics, which are free of ultraviolet divergences and which satisfy the unitarity and causality conditions. Estimates of the elementary length characterizing the degree of nonlocality of the theory were obtained. It was shown that non-local corrections do not play a major role in spinor electrodynamics.

An entirely different approach to the problem of constructing a non-local field theory was proposed by V. G. Kadyshevskiĭ in collaboration with A. D. Donkov, R. M. Mir-Kasimov, and M. D. Mateev. These authors considered a field theory in a momentum space of constant curvature. The behavior of the scattering amplitude at large momentum transfers was analyzed. A number of physical predictions were made for single-photon annihilation and deep inelastic scattering at ultra-high energies. The problem of gauge invariance of the theory was studied.

V. Ya. Feĭnberg and M. A. Solov'ev reported recent results concerning the local properties of Green's functions in theories with a non-polynomial growth; it has been shown that an exponential growth of the matrix elements in momentum space is inconsistent with the microcausality of the theory.

The next two days of the meeting were devoted to discussions of the fundamental consequences of dynamical symmetries in quantum field theory. Quantum field theory with a chiral-symmetric Lagrangian offers great scope for interesting physical applications. By allowing for a dynamical symmetry corresponding to the group $SU(3)\times SU(3)$ in constructing the interaction Lagrangian of the hadrons, it is possible to obtain a correct description of the strong, weak, and electromagnetic interactions of hadrons even in the lowest orders of perturbation theory, despite the presence of the strong coupling constant. M. K. Volkov and V. N. Pervushin reported a description of various physical properties of mesons in the framework of a chiral quantum theory. Interesting ideas on the relationship between chiral theories and phase transitions in the many-body problem have been developed by a French group (paper by J. Zinn-Justin).

The theory of gravitation was discussed in papers by B. DeWitt (England), E. S. Fradkin, N. A. Chernikov, and M. A. Markov. DeWitt considered the problem of quantizing a scalar field in an external gravitational field with a Schwarzschild metric. His results were applied to the problem of pair production by black holes. E. S. Fradkin and G. A. Vilkovyskiĭ carried out a canonical quantization of an arbitrary coupled dynamical system. Their expression for the S-matrix in the quantum theory of gravitation enabled them to establish the equivalence of the canonical and covariant formulations of gravitation. N. A. Chernikov succeeded in solving the equations originally proposed by Einstein for the coefficients of connectivity. He showed that the Born-Infeld equations for the electromagnetic field can be derived by equating the torsion covector to zero. M. A. Markov noted the interesting possibility of a nonlocality in the quantum theory of gravitation. An elementary length can arise in a natural way as a fluctuation of the metric at small distances without violating the microscopic causality of the theory.

Realistic models of supersymmetric theories have already been formulated, and these models provide unified descriptions of the weak and electromagnetic interactions. Such theories were discussed in papers by A. A. Slavnov, V. I. Ogievetskiĭ, and J. Lopuszanskii. A. A. Slavnov proposed a new general method of spontaneous supersymmetry-breaking. This method was used to construct a realistic supersymmetric model of the weak and electromagnetic interactions of hadrons. Different aspects of supersymmetries were considered by V. I. Ogievetskiĭ and E. Sokachev. These authors showed that the superfield is reducible in the superspin for a given external spin and conversely (the theory of duality). They also discussed the relationship between supersymmetry and gravitation. J. Lopuszanski (Poland) considered various representations of superalgebras in the axiomatic approach and the conformal superalgebra.

D. A. Kirzhnits and A. D. Linde presented a review of results concerning macroscopic effects on spontaneously broken symmetries in quantum field theory (an increase in temperature or density, and external fields or currents).

One of the most interesting prospects for explaining the constantly growing diversity in the world of elementary particles lies in the current search for particle-like solutions in field theory—solitons. An interesting method of finding soliton solutions which are not magnetic monopoles was proposed by L. D. Faddeev. The presence of a definite symmetry group implies the existence of so-called topological charges and currents. The topological charge must be non-zero for a stable soliton.

Various manifestations of solitons in problems of quantum field theory were described in a paper by A. M. Polyakov. This author discussed the possibility that soliton solutions in gauge theories may lead to the confinement of quarks within a limited volume.

Thus recent results in this field have shown that non-local objects can in principle be introduced in ordinary local but non-linear field theories by constructing exact solutions of the classical equations of motion.

One of the possible manifestations of nonlocality is a consequence of dual resonance models, whose development was stimulated to a great extent by strong-interaction dynamics. The principle of duality on which these models are based is a reflection of the experimentally confirmed fact that the sum of the resonances in one channel is equal to the sum of the resonances in another channel.

The principle of duality has led to the model of hadrons as non-local objects—strings. The mass spectrum of a quantized string reflects the classification of hadrons according to Regge trajectories, while the length of a string characterizes the slope parameter of a trajectory. We note that the string model is adequate for the Born-Infeld model (the latter had already been studied by B. M. Barbashov and N. A. Chernikov in 1965).

String models are now being widely investigated at both the classical and quantum levels (review paper by B. M. Barbashov and V. V. Nesterenko). However, attempts to describe the experimental data in terms of a mathematically consistent string model have encountered the following difficulties:

1) the existence of tachyons in the spectrum of states;

2) the exotic dimensionality (26, 10) of the space which admits a mathematically consistent scheme of relativistic quantization;

3) the fact that the problem of unitarizing the dual amplitudes requires a systematic treatment of the N-loop dual amplitudes and their regularization, i.e., the construction of a "quantum field theory" for strings.

An interesting idea of eliminating tachyons has been realized in work by a group of theorists at Kharkov (paper by D. V. Volkov *et al.*), who studied spontaneous vacuum transitions by introducing an additional interaction of a particle with the vacuum. It is well known that this procedure makes it possible to eliminate tachyon states in models of ordinary quantum field theory. The introduction of an interaction with the vacuum in a dual resonance model is reminiscent of the idea of subjecting an atomic system to an external magnetic field. The resultant splitting of degenerate energy levels indicates the presence of the spin degrees of freedom. A similar splitting of Regge trajectories is observed in dual models, corresponding to an additional classification of the quark lines in the dual diagrams according to the group $SU(N)$ with $N=1, 2, 3, \ldots$.

J. Scherk (France) presented an interesting review in which he discussed the possibility of using dual models to construct unified renormalizable theories of elementary particles and their interactions, including gravitation.

Many quark models to describe both high-energy and low-energy experiments have recently been proposed. However, the quark concept itself is interpreted in different ways in describing the data in different energy regions. We consider here both structure quarks and current quarks. The former are usually regarded as structural constituents of hadrons. They are used to describe low-energy physics, particularly in quark "bag" models of hadrons (review paper by P. N. Bogolyubov), i.e., extended quantum objects containing bound states of massive quarks. The first such model of quasi-independent heavy quarks was proposed about ten years ago at Dubna (N. N. Bogolyubov, A. N. Tavkhelidze *et al.*). These models provide a satsifactory description of the low-energy characteristics of hadrons, the form factors for various interactions, anomalous magnetic moments, etc.

Current quarks are identified with massless (or almost massless) partons and generally appear in unified field theories (such as the Weinberg theory). These ideas provide a basis for various analogies between quarks and leptons, which in turn can lead to neutrino oscillations (paper by S. M. Bilen'kiĭ and B. M. Pontecorvo). Processes involving large momentum transfers give direct evidence for a compound (parton) structure of hadrons at high energies (review paper by A. V. Efremov).

The asymptotic behavior of form factors, Bjorken scaling in deep inelastic processes, the behavior of cross sections at large momentum transfers (the quark counting rule of V. A. Matveev, A. N. Tavkhelidze, and R. M. Muradyan), and other data indicate that the quark-parton model provides an adequate description of the structure of hadrons.

One of the central problems of the theory of quarks is to relate the two different approaches based on structure quarks and current quarks. It was shown in a paper by A. T. Filippov that this problem can be solved in analogy with the microscopic theory of superconductivity of Bardeen, Cooper, Schrieffer, and Bogolyubov. In particular, the transformation between current quarks and structure quarks is a special case of the canonical transformation introduced by N. N. Bogolyubov. A dynamical spontaneous symmetry breaking in the quark model may be the starting point which could unify the quark models for the low-energy and high-energy regions. Dynamical spontaneous symmetry breaking in relativistic models is a field of study which is now becoming increasingly important and is attracting the attention of many theorists. I. Sogami (Japan) made use of the quark model to develop Yukawa's ideas for the case of multi-component systems. His formalism is used to calculate the S-matrix elements for hadronic processes.

Over 120 scientists from 13 countries took part in the meeting. A characteristic feature of the meeting was a wide range of discussions on some of the most interesting individual problems at special seminars, which were held almost every day after the close of the official program for the day. A general appraisal of the meeting was given at the concluding session by a number of participants (M. A. Markov, B. M. Pontecorvo, A. M. Baldin (U.S.S.R.), A. Ullmann (G.D.R.), Kh. Khristov (Bulgaria), and J. Zinn-Justin (France)). It was pointed out that periodic meetings of this kind are undoubtedly of great value for the fruitful exchange of ideas in quantum field theory.

The Publishing Department of the Joint Institute for Nuclear Research has published the proceedings[2] of the 4th International Meeting on Non-Local Quantum Field Theory, containing approximately half of the papers (22 out of 48) presented at the meeting. These proceedings consist primarily of the reviews mentioned in this summary.

[1]Materials of the 3rd International Meeting on Non-Local Quantum Field Theories, D2-7161, JINR, Dubna, 1973.

[2]Materials of the 4th International Meeting on Non-Local Field Theory, D2-9788, JINR, Dubna, 1976.

Translated by N. M. Queen