Unified string theories

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At the present time the idea that string theories can serve as a basis for constructing a single theory unifying in a noncontradictory manner all the fundamental interactions in nature is gaining great popularity. The book under review—the proceedings of a seminar on string theory which took place during July-August 1985 at the Institute for Theoretical Physics of the University of California in Santa Barbara (USA). The majority of the leading specialists participated in the work of the seminar and this produced a very high level both of the review lectures and of the original communications.

The book opens with a list compiled by D. Gross of the fundamental questions faced by string theory: What are the "first principles" of string theory? How many different string theories are there? How is covariant perturbation theory to be developed and how to go beyond its framework? Why is the vacuum of string theory so constructed that only four space-time dimensions are directly observable? Does the string theory reduce at "low energies" to a fully realistic four-dimensional unified theory in agreement with observations? Are there any specific "string" effects predicted by string theory? Are singularities which are present in the general theory of relativity absent in string theory? The first efforts to answer these questions are contained in the articles included in the book.

Approximately two thirds of the book are taken up by lectures on different aspects of the theory of (super)strings. The lecture of C. Thorn is devoted to an introduction to the theory of "first-quantized" boson strings. The formalism of "light cone parametrization" is presented in detail, as well as covariant quantization and the no-ghost theorem. The "discrete" formulation of the theory is also discussed in which the coordinate enumerating the points of the string is chosen to be discrete. The topic of the lectures by S. Mandelstam is the description of the scattering amplitudes of interacting strings with the aid of a fundamental integral in the light-cone gauge. Technical aspects of calculating multi-loop diagrams in the theory of boson strings which are needed, in particular, in proving the ultraviolet finiteness of the theory are investigated. The lectures of O. Alvarez give a review of the differential-geometry approach to string quantization based on the covariant functional integral over surfaces that are introduced by A. M. Polyakov. The choice of a covariant gauge and the reduction of the path integral (in the critical dimensionality) to an integral over a finite-dimensional space of moduli is described in detail.

The lectures by S. Shenker and D. Friedan are devoted to the application of methods of two-dimensional conformally-invariant quantum field theory (QFT) to string theory. A review is given by the basic concepts of conformal QFT (the energy momentum tensor, the Virasoro algebra and its representations, the operator decomposition, the condition of unitarity). The superconformal QFT is investigated in detail in connection with the Neveu-Schwarz-Ramond fermion strings. In particular, the concept of a super-Riemann surface is introduced, the structure of a superconformal ghost sector is investigated, and the BRST-quantization of fermion strings is developed (including the construction of a covariant vertex operator for fermion emission). The lectures of P. Goddard and D. Olive give an introduction to the theory of representations of Kac-Moody algebras and their applications to string theory. Questions are examined by constructing representations of the Virasoro algebra and the Fermi-Bose-equivalence in two-dimensional space.

An introduction to different aspects of superstring theory is given in the lectures by L. Brink and M. Green. The construction of a functional ("second-quantized") superstring theory in the light-cone gauge, is examined, as well as the cancellation of anomalies in single-loop diagrams in the theory of SO(32)-open superstrings, and also the cancellation of anomalies from the point of view of a low-energy theory of the field of $(D = 10)$-supergravitation, interacting with a supersymmetric Yang-Mills theory. A review of the theory of heterotic superstrings is given in the lectures by D. Gross. Vertex operators for the interaction of heterotic strings with external fields are constructed and a calculation is carried out of tree and single-loop scattering amplitudes for massless particles. The problem is examined of finding a low-energy effective Lagrangian for fields corresponding to massless excitations of a string, and corrections to the Einstein Lagrangian of the fourth order in curvature are found.

The two lectures by E. Witten "Topological tools in ten-dimensional physics" and "Unification in ten dimensions" are devoted to an analysis of possible consequences of the theory of ten-dimensional superstrings on the assumption of compactification of six spatial dimensions. The question of the origin of the quantum number "flavor" is discussed, as well as the properties of Yukawa constants, the existence of magnetic monopoles, the nature of Higgs bosons, etc.

More specialized articles (seminars) are collected in three sections: 1. Two-dimensional field theory and functional techniques, 2. String field theory, 3. String phenomenology. The greater part of the articles of the first section are devoted to an examination of first-quantized strings in external fields. The corresponding string actions refer to two-dimensional sigma-models. The papers by E. Martinec, P. Ginsparg, A. Sen, S. Wadia, I. Bars, and L. Mesincescu discuss conditions of conformal invariance (finiteness) of string sigma-models, and also the conditions for the conservation of classical symmetries of string action at the quantum level (taking into account loops of two-dimensional theory), i.e., conditions for the cancellation of two-dimensional anomalies. The article by J.-L. Gervais examines the rela-

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tionship between string theory and conformal-invariant two-dimensional theory. The papers by L. Mesincescu and W. Siegel analyze the problems of the theory of superstrings within the framework of the covariant formalism developed by M. Green and J. Schwarz.

The articles of the second section (the authors are W. Siegel, B. Zweibach and T. Banks, and M. Peskin) discuss different aspects of the second-quantized string theory in which the principal object is the string field—a functional of the contour in space-time. The necessity is emphasized of introducing an infinite set of string fields in order to obtain a local covariant action for a string field theory.

In the articles of the "String phenomenology" section phenomenological predictions of the theory of heterotic superstrings are analyzed within the framework of the scheme of compactification of the six "extra" dimensions onto the so-called Calabi-Yau space (a 6-dimensional Kähler manifold with the SU(3) holonomy group). In particular, a detailed discussion is given of the mathematical properties of the Calabi-Yau space (G. Horowitz), the correspondence at low energies with the grand unification theories (A. Strominger, C. Nappi, B. Ovrut) and other problems.

On the whole the book gives a quite complete idea concerning the level of development of superstring theory as of the end of 1985 and can serve as an introduction into this rapidly developing field of modern theoretical physics. It is of undoubted interest both for specialists, and also for those beginning the study of string theory.