Unification and supersymmetry

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Mohapatra R. *Unification and Supersymmetry: The Frontiers of Quark-Lepton Physics.* Ed. E. J. Redish, Springer-Verlag, Berlin; Heidelberg; New York; London; Paris; Tokyo, 1986 (Contemporary Physics).

The author of this book is a well-known theoretician working in the field of unified models. The book is based on a course of lectures given by the author in the course of several recent years at the City College of New York and at the University of Maryland (College Park). The author notes that the aim of the book is to provide an ordered presentation of a wide circle of ideas and methods utilized in constructing unified models of elementary particles. At the present time there are no unconditional criteria which would uniquely distinguish some one of the models of grand unification, and this is what determines the existence of a fairly large number of potentially possible extensions of the Weinberg-Salam theory. In such a situation the principal attainment of a theory concerned with the construction of unified models is not some specific scheme or other (not one of which can claim to be exclusive), but, rather, the entire accumulated arsenal of those methods and approaches which in going from model to model have demonstrated their viability and timeliness. The presentation in the book under review is constructed in an appropriate manner: its somewhat mosaic nature is determined by the present-day state of the problem. The author does not exclude from consideration models which in their present form do not satisfy all the requirements of experiment, if, nevertheless, the mechanism utilized in them is capable of describing some observed effects. As a result the reader has spread out before him a broad panorama of methods utilized in constructing unified models.

The book consists of sixteen chapters, the first eight of which, comprising approximately three fifths of the entire volume, are not associated with supersymmetry. This first part can also serve as an introduction into the subject for readers who are acquainted at least with the motivations for the proposed constructions and with the accompanying folklore (of course a lot more beyond this is assumed: the author himself mentions courses on quantum field theory, group theory, fundamentals of particle theory). The first two chapters briefly, almost at the level of establishing notation, introduce the basic concepts which will be needed for subsequent discussion: symmetries and currents in the Lagrangian field theory, local symmetries and Yang-Mills fields etc., following which, using specific examples, a circle of ideas is presented associated with spontanteous symmetry breaking and the Higgs mechanism. The third chapter is devoted to the Weinberg-Salam theory and the comparison of its consequences with experiment (deeply inelastic electron-hadron scattering, violation of atomic parity, suppression of the $K_L^0 \to \mu J \mu$, decay the $K_L - K_S$ mass difference, the $K_L \to 2\gamma$, decay etc.); the properties of Higgs bosons are also discussed here.

After discussing the standard facts the author goes on to a presentation of different variants of the answer to the question: what new physics is opened up beyond the limits of the Weinberg-Salam model? The fourth chapter discusses two aspects of CP-violation: the models of weak interactions capable of producing the experimentally observed CP-violation in kaon decay (the Kobayashi-Maskawa model, the right-left symmetric model, violation resulting from Higgs exchange, etc.), and problems associated with the θ parameter and with the axion in strong interactions. In addition a separate chapter is devoted to the right-left symmetric models which are an alternative to the standard $SU(3)_c \times SU(2)_c \times U(1)$-model. The motivation for examining right-left symmetric models includes considerations of the possible nonzero neutrino masses. Following the construction of the model the cosmological consequences are discussed of the nonzero neutrino mass, of the neutrinoless double β-decay, selection rules for processes with nonconservation of the baryon number, the violation of the lepton number and other low-energy consequences.

A chapter each is devoted to each of the two grand unification models: $SU(5)$ (group-theoretic aspects of the violation of $SU(5) \to SU(3) \times SU(2) \times U(1)$, the problem of hierarchy, the prediction for the Weinberg angle, the detailed analysis of predictions for proton decay, etc.) and $SO(10)$ (group-theoretic aspects, different intermediate stages of the $SO(10) \to \ldots \to SU(3) \times SU(2) \times U(1)$, violation, fermion masses). Finally, the eighth chapter introduces the reader to techniquarks, preons and different variants of the construction of composite models. Compared to preceeding chapters this chapter is more of a review nature.

Conceptual ideas establishing the connection with other fields of physics, or borrowed from them, are important as signposts in the search for the Correct Model. One of such guiding principles is the hypothesis concerning the (violated) supersymmetry that underlies the observed world. By now considerable progress has been achieved in the study and the understanding of a number of nontrivial properties (ultraviolet finiteness, problems of supersymmetry violation) of many supersymmetric theories which are, however, known to be unrealistic. It is natural to attempt to apply the mechanisms operating within them to models of elementary particles. A separate important place among the supersymmetric theories is occupied by different versions of supergravitation. Unification of fundamental interactions up to Planck energies in supersymmetric models might have been supplemented by including supergravitation, as a result of which the gravitational interaction would be included among the interactions being unified. In its turn (although

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this remains beyond the framework of the book under review) supergravitation together with other supersymmetric theories has recently begun to be seriously regarded as the low-energy limit of superstring theories upon which rests the final hope of a single and noncontradictory "theory of everything."

The second part of the book (chapters 9–16) is effectively devoted to supersymmetry, and begins with a condensed presentation of the basic ideas of $(N=1)$-supersymmetry, including concepts of superspace and superfields. Following this examples are constructed of supersymmetric field theories. The presentation is brought up to the Feynman rules and supergraphs. Here as in the course of the whole book, new concepts are introduced using simple examples, the presentation is aimed at ease of visualization and not at achieving maximum generality. The short but important tenth chapter deals with violation of supersymmetry which is needed in realistic models. The Fayet-Iliopoulos and O'Raifeartaigh mechanisms of spontaneous supersymmetry breaking are described, the result of investigating which is the conclusion in favor of the "soft" supersymmetry violation. After this the presentation is concentrated around the "soft" violation as a result of introducing masses (of scalar particles or calibrino) or of trilinear scalar interactions. A separate chapter is devoted to the model with "soft" violation which is a supersymmetric extention ("doubling") of the $SU(3)\times SU(2)\times U(1)$-model. Here masses of fermions-superpartners and the phenomenological limitations on them are discussed, in connection with which a number of processes is examined with participation of superpartners (altogether approximately thirty Feynman tree diagrams). Also other possible manifestations of supersymmetry are briefly touched upon as illustrations.

One of the main functions, the execution of which is relegated to supersymmetry in unified models, is the solution of the hierarchy problem. Progress along this line is discussed in the chapter devoted to supersymmetric extensions of the $SU(5)$ grand unification model. However, a new difficulty is the degeneracy of vacuum, and this, generally speaking, creates a cosmological problem. Proton decay is also examined in the super-$SU(5)$ model whose principal mode is different compared with the nonsupersymmetric variant.

The fourteenth chapter introduces the local $(N=1)$-supersymmetry which leads, as is well known, to supergravitation, the procedure of constructing which is briefly indicated here together with an indication of the principal facts concerning the 3/2 spin field and the general theory of relativity. At the level of a compilation of results conformal supergravitation and the interaction of supergravitation with matter (in terms of component fields) are also introduced. Here also is determined the subject of further analysis—the scalar potential. The next chapter is devoted effectively to the application of $(N=1)$-supergravitation to the physics of particles the main motif of which is the connection of the scale of violation of electroweak symmetry with the gravitino mass (i.e., the parameter of supersymmetry violation), and the scale of the grand unification with the Planck mass.

The last chapter contains a brief overview of possible generalizations of the $(N=1)$-supergravitation: The existence of $(N>2)$-supergravitations and supergravitations in higher dimensions is pointed out, but without a discussion of the connection with realistic models. Also the existence is mentioned of a ten-dimensional supersymmetric Yang-Mills theory free from anomalies and of supergravitation with the gauge group $SO(32)$ or $E_8\times E_8$. The further development of this theme is the subject of contemporary investigations on the applications of superstring theories.

The book contains two (!) exercises; in actual fact serious independent work is required of the reader, which is aided by a quite extensive bibiography to which the author himself continually refers. The reader who has puzzled out to the end all the examples being considered will be able to study unified models independently.

Translated by G. M. Volkoff