A MATHEMATICAL FRAMEWORK THAT MAY BE A 'THEORY OF EVERYTHING'

Superstring Theory Volume 1: Introduction Volume 2: Loop Amplitudes, Anomalies and Phenomenology

Michael B. Green, John H. Schwarz and Edward Witten
Cambridge U. P., New York, 1987. 469 + 596 pp.
$39.50 hc ISBN 0-521-32384-3;
$49.50 hc ISBN 0-521-32999-X

Reviewed by Paul H. Frampton

Who would have guessed in 1968 that a schematic formula proposed that year for the four-hadron scattering amplitude would lead almost 20 years later to a theory that unites gravity with the electroweak and strong interactions? Superstring theory, the most recent in the series of remarkable developments that started with that formula, is today the leading candidate for such a unified theory. [See the article by John Schwarz on page 33.] Whether or not superstring theory turns out to be correct, its ideas are surely remarkable for their lack of any teleological evolution: Superstring theory is still a theory of S-matrix amplitudes just as string theory has always been since it was introduced in 1970. This lack of a fundamental basis makes it impossible to write a book on superstring theory with the logical structure possible in general relativity or gauge field theories. For superstrings, one has neither guidance from experiment nor a satisfactory formulation of the underlying assumptions as a set of axioms. But one does have a brilliant mathematical framework, which—remarkably—contains within it both general relativity and gauge field theories.

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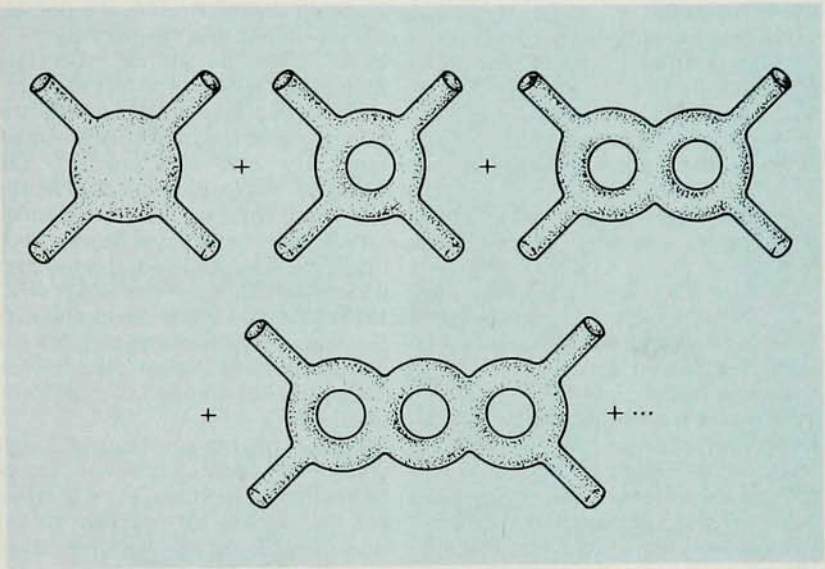

Superstring diagrams. This example shows the loop expansion for elastic scattering of two gravitons. (Reproduced from *Superstring Theory* by permission of the publisher.)

String theory is enjoying a greater level of popularity today than ever before. All three authors of *Superstring Theory* are probably aware that progress in superstring theory may be so rapid that parts of their book will soon be obsolete.

For convenience, the book is divided into two volumes (chapters 1–7 and 8–16). In terms of actual content, I would characterize chapters 1–11 as formalism and chapters 12–16 as applications of superstring theory.

Chapter 1 provides an overall introduction. Surprisingly, this chapter devotes only 13 pages to the first era (1968–74) of string theory—surprising because the two basic strings, the 26-dimensional bosonic string and the 10-dimensional fermionic string, were both discovered during that time. Of course, our understanding was much less then; for example, the fermionic string was inconsistent because it lacked a crucial projection operator. Nevertheless, the currently fashionable superstrings are based on these old models. Chapters 2 and 3 cover quantization of the bosonic string, which is unquestionably the proper way to begin an introductory course on string theory. Weyl invariance and background fields are treated well. Chapters 4 and 5 quantize the superstring and provide good explanations for why light-cone gauge is still better understood than covariant quantization. Chapter 6 is on non-Abelian gauge groups. I would have preferred to see the entire chapter devoted to the origin of the gauge group in the heterotic string, which is a truly new discovery of the second era (1984 onward) of string theory. Chapters 7–9 give explicit calculations of tree diagrams and one-loop diagrams with four external legs for the bosonic string, superstrings and heterotic strings.

Chapter 10 discusses cancellation of gauge hexagon anomalies, a topic in whose development I played a role, and I have a criticism here that is more than just organizational: For open superstrings the orientable nonplanar diagram is finite and not

anomalous, but the regularization of the annulus and Moebius-strip hexagons is not yet understood. In closed string theories one knows both their finiteness and freedom from anomalies. For the O(32) open superstring case, therefore, I find that the stringy regularizations of chapter 10 are unconvincing. The low-energy effective field theory calculation, discussed in chapter 13, is much clearer.

Chapter 11, rounding out the formalism, provides a derivation of Stanley Mandelstam's useful technique for explicit string calculations in the light-cone gauge.

The second half of the book concerns applications of superstrings and is necessarily more speculative. Curiously, one may regard the applications either as phenomenology—because they attempt to link the theory with experimental physics—or as mathematics—because differential and algebraic geometries come to the fore here.

Chapter 12 is an excellent treatment for physicists of the mathematics of differential geometry and differential forms using examples of gauge fields and spin-$\frac{1}{2}$ fermions. Chapter 13 contains a general account of the low-energy effective theory, particularly of the anomaly cancellation already mentioned. The compactification of six spatial dimensions is discussed in chapter 14, with particular stress on index theorems and the occurrence of zero modes. Chapter 15 explains the choice of Calabi–Yua manifolds for the compactified dimensions and explains how the heterotic string can lead to a supersymmetric E(6) grand unified theory with sensible quantum numbers for quarks and leptons. The final chapter explores several further phenomenological implications, for example, how in the E(6) scenario the renormalization group dictates that there be no more than three quark–lepton families—otherwise the gauge couplings would blow up at energies well below the Planck energy.

Without hesitation, I can rate the Green–Schwarz–Witten book as elegant and useful. Its timely publication could have a significant impact on the development of superstring theory. While it is obviously not the last word on the subject, I hope that the book will inspire a bright student to answer one of the basic outstanding questions, such as:

▷ Why does the cosmological constant vanish after supersymmetry breaking?

▷ How does one locate the correct vacuum state from the billions of candidates in the superstring theory?

▷ What are the axiomatics that allow superstrings to generalize general relativity and gauge field theories?

Introduction to Supersymmetry and Supergravity

Peter West

World Scientific, Singapore (Teaneck, N. J.), 1986. 289 pp. $32.00 hc ISBN 9971-50-027-2; $19.00 pb ISBN 9971-50-028-0

Through the cooperation of a number of researchers and the persistence of Peter West, its author, this long anticipated book has at last appeared and makes a very creditable effort to fill a niche in the literature on supersymmetry and supergravity. The book fits nicely in level of difficulty and detail between the more elementary *Supersymmetry and Supergravity* by Julius Wess and Jonathan Bagger (Princeton U. P., Princeton, N. J., 1983) and the more comprehensive *Superspace* by Marc Grisaru, Martin Roček, Warren Siegel and myself (Benjamin–Cummings, Menlo Park, Calif., 1983).

West, a physics professor at King's College in London and a well-known researcher in the area, gives a coherent and logical introduction to the subject with enough detail to illustrate the structure of supersymmetrical field theories. An example of the attention to detail is seen in the discussions of the difference between algebraically on-shell and off-shell component actions in chapters 5 and 12. Another such example is found in the appendix, which gives the proper definition of superspace complex conjugation. A lack of appreciation of this definition has often caused confusion and unnecessary complication in the literature on the superspace formulation of such theories. The range of topics treated is broad enough that the nonspecialist or intermediate-level graduate student will begin to understand the intricacies of the field.

The book proceeds from general discussions to representation theory and construction of supersymmetric models. Unfortunately, West's discussion of the superconformal algebra contains an error that causes a problem in a later "proof" of the finiteness of $N = 4$ Yang–Mills theory. However, he also gives several alternative proofs to support the arguments for the finiteness of both the $N = 2$ and $N = 4$ Yang–Mills theories. With effort, the reader unfamiliar with supersymmetric perturbation theory can learn the technique of Feynman supergraphs. Curiously, however, the presentation does not use the most recent (and efficient) calculational rules. West describes the implications of supersymmetry for quantum field theory clearly and concisely.

Leaving rigid supersymmetric theories, West moves on to the theory of supergravity. The treatment given more or less follows the historical development. The widely used method of tensor calculus is treated in an erudite manner. Undauntedly, West tackles the challenge of elucidating the structure of superspace supergravity. Here the discussion roughly parallels the treatment of Wess and Bagger. However, West pays much more attention to the nature and role of the constraints imposed on the theory. The only disappointment is that although there is much discussion of constraints, almost no effort is made to solve them. Similarly, West gives insufficient attention to how superspace generalizes and underlies the tensor calculus method.

With the impact of string theories, it was perhaps unavoidable that the book would include some discussion of strings. In the final two chapters, where this topic is treated, the book fails to maintain the high standards set by preceding chapters. An example is the discussion of the patently false notion of a finite set of auxiliary fields for the bosonic string. The discussion of two-dimensional supersymmetric models is truncated and not particularly systematic.

Overall this book is a valuable contribution. The principle of supersymmetry has had a major impact on theoretical particle physics over the last decade and will likely continue to do so for the foreseeable future. *Introduction to Supersymmetry and Supergravity* offers a way for a wider audience to gain access to and understanding of this principle.

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The Second Creation: Makers of the Revolution in 20th-Century Physics

Robert P. Crease and Charles C. Mann

Macmillan, New York, 1986. 480 pp. $25.00 hc ISBN 0-02-521440-3

The last few years have seen the appearance of an impressive number of books that try to explain what is happening in modern physics to the lay audience that one always hopes is waiting out there. These are fine,