Weinberg on Supersymmetry; Another Landmark Work

The Quantum Theory of Fields, Vol. 3: Supersymmetry

Steven Weinberg
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Reviewed by Frank Wilczek

One might not be predisposed to describe the third volume of Steven Weinberg's treatise on quantum field theory as "long-awaited," since the first two volumes (*Quantum Theory of Fields 1, 2*, Cambridge U. P., New York, 1995, 1996) appeared fewer than five years ago. Upon beginning to read the final volume in Weinberg's trilogy, however, I soon realized that he has produced a treatise that many of us had indeed long awaited, perhaps without fully realizing it.

Twenty-eight years ago Weinberg produced a landmark text on relativity theory, his *Gravitation and Cosmology*, (Wiley, 1972). That subject-matter had, of course, been the focus of several previous texts, but Weinberg's treatment was unique in important ways. It was self-contained in its logic, complete in its derivations, scholarly, and—last but by no means least—judicious in its choices. In a field that easily lends itself to ungoverned speculation and purely formal elaboration, Weinberg kept steadily oriented toward observed or potentially observable phenomena. His focus on relativistic stars and, especially, physical cosmology was prescient; these subjects flourished in ensuing years, in large part through the efforts of a generation influenced by *Gravitation and Cosmology*.

Now, I believe, with the publication of *The Quantum Theory of Fields, Vol. 3*, he has performed an analogous service for supersymmetry.

Supersymmetry, in the sense used by Weinberg and followed here, is a particular extension of Lorentz invariance. It allows transformations between particles with different spins. In particular, supersymmetry transforms fermions into bosons and *vice versa*. Very elementary observations are sufficient to inform us that supersymmetry is not an exact symmetry of Nature. For example, if there were bosonic particles having the same mass and charge as electrons, they would have been detected long ago. But a great lesson of twentieth-century physics is that fundamental symmetries of physical laws can be hidden or broken in a variety of ways and yet remain extremely useful. For example, within quantum chromodynamics one has confinement of color symmetry, and within electroweak theory (or within a superconductor) one has spontaneous breaking of gauge symmetry.

Are there any indications that a similar development will occur for supersymmetry? There are indeed, as Weinberg emphasizes. Supersymmetry, so long as it is "softly" broken, arranges that quantum corrections due to highly virtual bosons and fermions cancel, and it suppresses certain kinds of radiative corrections that are otherwise generic. Among these are radiative corrections to the scale of electroweak symmetry breaking, which one would otherwise expect to be quite large. This mechanism for suppressing unwanted radiative corrections works quantitatively only if the supersymmetric partners of known particles are not too heavy; specifically, they do not exceed the reach of the Large Hadron Collider (LHC) planned for CERN. Moreover, there is already impressive, although indirect, quantitative evidence for the existence of such particles, from their role in ensuring the unification of couplings.

Weinberg builds up the necessary formal apparatus clearly and systematically, carefully motivating and stating the assumptions at each stage and delimiting the scope of each one. Recently there has been a tendency in certain quarters to label this restrained, selective approach "phenomenology." I prefer the traditional, appropriate usage: theoretical physics. Weinberg is a master theoretical physicist, and this book is a model work of theoretical physics.

The first part of the book, occupying almost two-thirds of its length, culminates in the construction of supersymmetric versions of the Standard Model and its extensions to include unification of gauge interactions. This part begins with a discussion of the uniqueness of supersymmetry as an extension of Lorentz invariance and works through the representations of supersymmetry algebras, their embodiment in quantum fields, and the construction of invariant interactions.

How and why is supersymmetry broken? Several options are discussed, but none is entirely convincing. In the absence of a canonical model for why and how supersymmetry breaking occurs, the predicted consequences of supersymmetry are not sharply defined. In particular, we cannot reliably estimate supersymmetric contributions to rare flavor-changing processes, including nucleon decay. On the face of it, they appear dangerously large. Nor can we fully pin down the tantalizing possibility that the lightest superpartner provides the astronomers' "dark matter." Supersymmetry breaking remains a great open problem.

The remainder of the book is divided roughly equally between nonperturbative aspects of supersymmetric quantum field theories and the extension of supersymmetry to include gravity (supergravity). Nonperturbative supersymmetry is of interest both because it provides insight to the way supersymmetry might be spontaneously broken and because it provides some surprisingly tractable models of general quantum field theoretic phenomena. Supergravity is of interest not only because (after all) gravity exists, but also because the gravitational interactions play a central role in some proposals for supersymmetry breaking. Quantum gravity might thus finally, albeit indirectly, enter the ambit of accessible laboratory phenomena. In many ways supergravity assumes its most beautiful form only when formulated in large numbers of dimensions (10 or 11), and Weinberg concludes with an incisive discussion of this aspect, with a pointer toward string/M theory.

Although this volume is the third in a trilogy, it is quite different from its two predecessors, and it stands on its own. It seems much closer than the others to being a true textbook and could work well with any of several excellent quantum field theory texts as its front end. May a new generation of students imbibe its content and spirit, and may it become the user's manual for the Large Hadron Collider!

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