BOOK REVIEWS

Field Theory for Today

The Quantum Theory of Fields. Volume 1, Foundations. STEVEN WEINBERG. Cambridge University Press, New York, 1995. xxvi, 609 pp. $49.95 or £35.

Quantum field theory is the language of relativistic quantum mechanics, the appropriate language for any quantum mechanical system in which the number of particles can change. Every student of theoretical physics should wrestle with it. In fields like particle theory and modern condensed matter theory, it is one of our indispensable mathematical tools. Yet for over 20 years there has been no good modern textbook on the subject. For all that time, Steven Weinberg has been promising to write one. That he has finally done it, at least a first volume (a second, subtitled "Modern Applications," is due in 1996), is cause for celebration among those who try to teach and try to learn the subject. Weinberg's book is for serious students of field theory. It will not be easy reading for anyone. But it is the first textbook to treat quantum field theory the way it is used by physicists today.

The history of quantum field theory, and thus of its textbooks, has been oddly twisted by the spectacular success of its first example, quantum electrodynamics, (QED), the theory of the interactions between electrons and light. Born late in the 1920s as a natural melding of quantum mechanics with Maxwell's electrodynamics, QED was initially plagued by "infinities"—apparently infinite answers to apparently physical questions. But soon after the Second World War Bethe, Feynmam, Schwinger, Tomonaga, and others understood in detail how to absorb the infinities by "renormalization" into two finite measured parameters (the charge and mass of the electron). Renormalization is done order by order in a small parameter, the famous $\alpha \approx 1/137$. This transformed QED into a calculational scheme. The predictions of renormalized QED matched experimental results with incredible precision.

On the one hand, the astonishing success of QED suggested to many physicists that the principles on which it was built should be inviolate axioms. In particular we thought that in any consistent quantum field theory the infinities must be absorbable into a finite number of measurable parameters. A theory of this kind is called "renormalizable." On the other hand, it was clear even as the quantitative evidence for QED grew that other interesting physics was going on in parallel that could not be described by a QED-like theory. For strong interactions that produce complicated scattering of protons, neutrons, and other similar particles and weak interactions that cause β-radioactivity, no consistent quantum field theory description was found for 20 years after the apotheosis of QED. QED stood as both the canonical definition of a relativistic quantum field theory and as the only example of a successful one. The textbooks of the early '60s reflected this odd situation, treating QED in detail while almost apologizing for quantum field theory in general.

Things changed dramatically in the early '70s. In a few years we went from having no consistent theory of weak interactions and no dynamical understanding of strong interactions to what we now call the standard model, a renormalizable theory that accurately describes the strong, weak, and electromagnetic interactions (Weinberg shared the Nobel Prize in 1979 for his part in this development). It even suggests how they might all appear as part of a single, unified interaction at very short distances.

Yet in spite of the success of the standard model, we no longer think that a quantum field theory must be renormalizable to be useful. This should sound surprising, because a theory that is not renormalizable has an infinite number of parameters. How can such a theory yield any predictions? The answer is that there is a natural ordering of the parameters. The parameters of the renormalizable theory are the most important. There is then a set of almost renormalizable parameters whose contributions to any physical process are suppressed by a small factor proportional to the energy. Then less renormalizable parameters give even smaller contributions, proportional to the square of the energy, and so on. Thus in practice only a finite number of parameters are required to describe processes at a given energy. As the energy increases, more parameters are required, until eventually, at some high energy cut-off, the theory is no longer useful. Such a theory is called an "effective field theory" because it is effective only in a limited domain of energies.

An effective theory cannot be the final "theory of everything" because it is not valid at arbitrarily high energies. But that should not bother us. There is no reason to believe that a theory of everything (assuming such a concept even makes sense) is a field theory at all, rather than a string theory or something else that we cannot yet imagine. What we do know is that at the energies we can probe today and at any energy at which special relativity and quantum mechanics are accurate we can describe the physics with a quantum field theory. This is the central message of Weinberg's book. He was one of the pioneers in looking at field theory in this way, and he has used this approach to great effect in his many important contributions to particle physics. The student who absorbs this way of thinking will find it both intellectually satisfying and very useful.

For example, as Weinberg discusses, we now explain the success of QED not by incanting an arbitrary principle (renormalizability) but by observing that the electron is much lighter than any other electrically charged particle. If we look at the interactions between electrons and photons at low energies (too low to produce any heavier charged particles), we can describe the physics by an effective field theory of electrons and photons and nothing else. All the rest of the physics of the standard model and beyond can be absorbed into the parameters of this effective theory. When the energy is very low (far below any other charged-particle masses), only the renormalizable interactions are important. Thus renormalizable QED is a good approximation. In a sense, therefore, Weinberg explains *why* QED looks the way it does. Of course, this is only a partial explanation. We still have no idea why the electron should be so much lighter than all other charged particles. This is but one example of a deep mystery about the world at short distance. Why is there interesting physics at so many very different energy scales? The ratio of the mass of the recently discovered t quark to the mass of the electron is almost 400,000,000. Why? There is much that we still do not understand.

Howard Georgi
Lyman Laboratory of Physics,
Harvard University,
Cambridge, MA 02138, USA