Foundations of Physics, Vol. 26, No. 3, 1996

Book Review

An Interpretive Introduction to Quantum Field Theory. By Paul Teller. Princeton University Press, Princeton, New Jersey, 1995, x + 176 pp., $35.00 (hardcover).

This excellently structured and very well-written book provides a concise but probing introduction into the fundamentals of quantum field theory. The expository material on the conceptual basis and formal elements of the theory is accompanied by a thoughtful philosophical critique that provides insight into such issues as the degree to which quanta can and cannot be thought of as particles in the classical sense, the ways in which a quantum field must be distinguished from a classical field, the care one must take in interpreting the content of Feynman diagrams, and the directions in which one can seek for understanding of the nature of renormalization.

The book will be accessible to the reader familiar with the general apparatus of ordinary quantum mechanics (observables as operators, the Hilbert space of states, the interpretation in terms of probabilities of eigenvalues as observables upon measurement). In some places the exposition and comment is quite condensed, however, and will probably be more useful as reflective critique to someone already familiar with the issues than to someone encountering the debates for the first time.

A first chapter outlines the author's general approach to theories and provides a useful overview of the remaining chapters. The author expresses sympathy for the view, proposed by Cartwright and Giere among others, that is skeptical of the claim that science aims at true exhaustive laws-of nature. Rather, theories are taken to be collections of "models" described by laws of limited applicability. Nature is represented to the degree that the models are "similar" in various respects to real systems. Neutrality is professed with regard to issues of realism. Then each of the later chapters is briefly summarized.

Chapter 2 centers on the following questions: What must be eliminated from the classical notion of a particle in order that we have the

0015-9018/96/0300-0423$09.50/0 © 1996 Plenum Publishing Corporation

appropriate concept of a quantum in quantum field theory? How should the mathematical apparatus that we are first led to in expressing quantum field theory be best reconstructed to meet this conceptual revision? The philosophical discussion of the traditional notion of substance in its various guises (as bearer or properties, as generator of identity over time and through change) is concise and accurate. The ways in which the quanta of quantum field theory lack "primitive thisness" (no exact particle trajectories, statistics failing to count as distinct states differing only by identical particle permutation, etc.) are thoughtfully outlined. The "labelled tensor product Hilbert space" formulation is criticized for its "superfluous structure," allowing as it does states nonsymmetric (or antisymmetric) under permutation that must then be eliminated. Quanta are emphasized to be entities that can be aggregated ("How many?" makes sense) but not ordered, labelled, or counted in the classical sense.

Chapter 3 presents Fock space with its basis in "number of particles in a given state" vectors as the ideal framework for quanta as earlier described. The vacuum state, raising and lowering operators and their commutation relations, the particle number operator, and the role of position as state parameter are introduced clearly and concisely.

Chapter 4 builds up time-independent and time-dependent fields of operators on the basis of the apparatus previously introduced. The field equations are explained. Then the reader is shown how the results obtained so far can be reached in an alternative manner, the manner actually followed historically. We could start with classical fields, Fourier analyze them, and quantize the results to get the raising and lowering operators. Or we could follow the route of second quantization, quantizing the wave solutions to ordinary quantum wave equations. Microcausality and the spin-statistics theorem are briefly discussed. The difficulty in characterizing quanta as localized in the relativistic theory (localization operators not Lorentz invariant for massive particles and nonexistent for mass zero) is noted.

Chapter 5 begins with important philosophical comments on the nature of a quantum field. An operator-valued field by itself amounts to a field of "determinables," not to an assignment of determinate quantities to each spacetime point. A field configuration (the field bracketed by a state on left and right) is an assignment of expectation values to the spacetime points. But even then the field configuration only represents the "propensities," the probabilities for obtaining specific values at the spacetime points when a measurement is performed. Then some field phenomena are described (vacuum polarization, Rindler quanta detected by an accelerated observer in a Minkowski vacuum state). The relativity of number of quanta to the state of motion of the observer due to the latter phenomenon is noted.

Chapter 6 takes up interactions and introduces the reader to such aspects of the formalism as the interaction picture, the S-matrix, "in" and "out" states, and the unitary time-development operator, Haag's theorem (a result that makes it clear that there cannot be a single Fock space representation for both the idealized asymptotic free in- and out-states and for the interpolated interaction states and thereby leads to grave difficulties for solutions to the axioms of quantum field theory that represent interactions) is noted and attempts to get around it (such as the LSZ approach) briefly outlined. Normal ordering is noted. Perturbation theory is explained and the role of Feynman diagrams in classifying terms in the perturbation expansions clearly explained. An excellent critical section warns the reader against reading off the intermediate particles (the "virtual particles") of Feynman diagrams as if they were some kind of real constituent of nature. As the author aptly points out, each Feynman diagram itself represents an infinite number of components of a vast superposition (we must integrate over all spacetime points) and is itself only one term in a perturbation expansion. "Analytic parts" (such as Fourier components of a function) are distinguished from "mereological parts" (such as spatial pieces of an object). I am not sure, however, that the distinctions made here are what ought to lead us to be suspicious of Feynman diagrams as representing real "ontological pieces" of the world. My suspicion is that the real need for ontological skepticism comes about from the fact that the field configuration as a whole is still nothing but propensities toward measured values in the orthodox interpretations.

Chapter 7 takes up renormalization. How infinities arise in the theory and how they are dealt with is explained. Three alternative ways of thinking about renormalization are suggested. The third of these, "the mask of ignorance" approach, fits nicely with the author's view of all theories as having limited domains of applicability. It would have been nice had the author supplemented this material with more on the "effective field theory" approach in which each quantum field theory is thought of as only good up to a certain energy, as having small but ignorable nonrenormalizable parts, and as having its parameters, plugged in by renormalization to observed mass and charge, actually determined by some unknown higher energy and more complete theory.

While the author professes neutralism with regard to issues of general philosophical realism, his interpretation is not neutral with regard to Bohrian versus "realist" interpretations of quantum mechanics. Taking field configurations to be merely dispositional with regard to measured quantities, without any underlying actuality of hidden variables to ground the dispositions, is opting for at least some of the Bohrian schema. Consider the alternative, for example, of Bohm's version of quantum field theory for boson fields. Here the field magnitudes are actual values over configuration space points, and not mere potentialities for results upon measurement.

It is interesting to note how quantum field theory puts even more pressure on realist (in the Bohm sense) accounts than does ordinary quantum mechanics. With each successive advance we make we are pressed to give up more and more of our classical realism. Consider the absence of "thisness" for particles and of nice localizability for them, the need to abandon even Fock space when interaction is taken into account, the relativity of particle number to state of motion of the observer, and the absence of free particles altogether in curved spacetimes. All of these factors push us in the direction of an account in which local responses of detectors are coupled together by pure potentialities, and push us in the direction of a "net of algebra of local operators" formalism (Haag) that matches this Bohrian ontology. From this perspective, Fock space is still too rife with surplus structure to represent what is left of our notion of a substantial world.

The reader who wishes to pursue the philosophical consequences that ensue when not only properties of things but the things themselves become subject to quantum superposition can do no better than to begin with Teller's book. Its combination of careful exposition and thoughtful philosophical critique is an ideal starting place for this inquiry.

Lawrence Sklar
Department of Philosophy
The University of Michigan
Ann Arbor, Michigan 48109-1432