field theory and its application to elementary particle physics through Feynman diagrams. (The title is evocative of the famous 1973 CERN yellow report *Diagrammar* by Gerard 't Hooft and Martinus Veltman, which has been the standard guide for understanding dimensional regularization and the Feynman rules of gauge field theories for high-energy physicists ever since.) The approach is constructive rather than deductive, and the book offers many fine insights into the physics content of results that may be thought of as purely mathematical. It is a good supplementary text for a beginning graduate student, but it cannot replace a standard text that takes a more conventional approach.

The explanations of such fundamental concepts as Lorentz invariance, commutators, Hilbert space, propagators and the like are very well done. At virtually every new step, there are clear statements regarding the assumptions and potential pitfalls. Explicit discussions of the constraints imposed by Poincaré invariance, gauge invariance, unitarity and causality pervade the book, helping the reader to appreciate the physical foundation of the formalisms involved. On the other hand, new equations often appear out of the blue (such as the gamma matrices in section 4.1) or with only plausible arguments for their correctness (such as the equations of motion in section 3.5). This will undoubtedly be confusing and mysterious to the uninitiated reader.

The strength of this book is in its detailed examples. Whereas the origins of many expressions and equations are not entirely clear, the subsequent calculations that result in such physical observables as cross sections and decay rates are very instructive and very clear. There are also many exercises throughout the text. The only shortcoming here is the author's insistence on using a space–time metric where $x_4 = ict$. The appearance of this imaginary fourth dimension requires special handling in a quantum framework, because complex conjugation appears often; the practitioner of this metric must remember that four-vectors must not be complex-conjugated, whereas the four-dimensional antisymmetric tensor $\epsilon_{\alpha\beta\mu\nu}$ must be considered imaginary. Some people will find this an unreasonable burden and a possible source of calculational error.

After the first four preliminary chapters the author plunges into a number of selected topics and examples of particular interest in elementary particle physics. Again the uninitiated student is likely to be overwhelmed by the sheer volume of seemingly unrelated and arbitrary facts. On the other hand, a student already familiar with the basic structure and systematics of the standard model of elementary particle interactions will find the many detailed discussions valuable and illuminating; these include pion decay and the triangle anomaly, the Lamb shift and the correction to the ρ parameter due to the top quark (a topic of current research interest). There is a very nice discussion of the problem of requiring both Lorentz invariance and unitarity for the interacting massless photon, which is resolved by gauge invariance with its associated Ward identity. There is also a nice example showing how the form of the propagator is actually related to unitarity and how the latter also requires the interaction Hamiltonian to be Hermitian.

There are five appendices, the last one being a catalog of the various terms of the Lagrangian of the standard model. Since no discussion of non-Abelian gauge symmetry or the Higgs mechanism has been given, this will again appear baffling to the beginning student. If the reader of *Diagrammatica* already has a working knowledge of the standard model, or at least of quantum electrodynamics, then it does offer complementary insights into the interconnectedness of fundamental physical principles and will be an excellent choice for learning how to do some detailed calculations.

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Quantum Mechanics: Historical Contingency and the Copenhagen Hegemony

James T. Cushing
U. Chicago P., Chicago, 1994. 317 pp. $27.00 pb ISBN 0-226-13204-8

The standard formalism for quantum mechanics—a state vector Ψ evolving via the Schrödinger equation in a Hilbert space $\mathcal{H}$, with observables as operators on that space—was consolidated in the late 1920s by Werner Heisenberg, Niels Bohr, Wolfgang Pauli and their associates, the Copenhagen School. It is, in terms of prediction, the most outstandingly successful theory in the history of science. The well-earned prestige of quantum mechanics (and its inventors) guaranteed widespread assent, at least as lip service, to the interpretation, although there have always been mutterings of discontent. But as the formalism won acceptance, it brought along for the ride the "Copenhagen interpretation," a worldview that belongs more to metaphysics than to physics.

One of the postulates of Copenhagen dogma—apparently backed up by John von Neumann's no-hidden-variables theorem—is that no deterministic theory allowing for actual particles moving in well-defined trajectories can be consistent with the formalism. This dictum has been repeatedly challenged, most successfully by David Bohm's work of the early 1950s. This work and its subsequent amplification by others have created a (nonrelativistic) Schrödinger-equation-plus-dynamical-system model, wherein particles and their trajectories are quite "real." True determinism reigns. Amazingly, the Hilbert space formalism is a corollary.

Quantum Mechanics: Historical Contingency and the Copenhagen Hegemony, James T. Cushing's wonderful book, explores this curious situation from a number of viewpoints: physics, philosophy and history. Cushing tells three main stories, one of them fictitious. He recounts the rise of the Copenhagen hegemony, even in the teeth of Albert Einstein's opposition, and of promising beginnings toward deterministic models. He summarizes Bohm's work and the story of its unfair neglect—which is still the general rule. Finally he contrives a quite plausible "alternative history" showing that something very like Bohmian mechanics could have been developed around the time of the celebrated 1927 Solvay Congress. The germinal ideas—and the brains—were all there.

Cushing accomplishes this not through loose narrative but through a marvelously concise exposition that takes full account of the technicalities. Nearly one-fourth of this text consists of appendices that present fully mathematical accounts of the chief points at issue. Cushing is relentless and bracing. He touches on virtually all the issues with pinpoint accuracy and no waste of words.

For the record, Cushing states his lack of partisanship for either the Copenhagen or the deterministic interpretation. The alert reader will note, however, that this is rather like Marc Antony's neutrality with respect to Caesar and Brutus. Clearly Cushing sees in the Copenhagen orthodoxy a substantial amount of wrongheadedness, frequently backed up by hot air. He gives the game away when he notes that, had Bohmian dynamics been available before the Copenhagen doctrine hardened, any subsequent formulation of a Bohr-like *weltanschauung* would have been regarded by the physics community as a contrarian philosophical fidget of no real importance. That things fell out otherwise is Cushing's "historical contingency."

I do have some quibbles. For the sake of his meditations on underdetermination and theory choice, Cushing minimizes important distinctions between the Copenhagen doctrine and Bohm's work. The Copenhagen interpretation is a philosophical gloss on a predictive formalism; Bohmian mechanics, by contrast, is a rigorous mathematical model that entails that formalism. Bohm is to the formalism as Newton is to Kepler's laws, a point that Cushing should have made clear. This is not merely a philosophical point; it has important implications for future work on the foundations of physics, work that, in my view, must take up the problems that were largely sidetracked decades ago as a consequence of Copenhagen *hauteur*. In this context the Copenhagen view is unlikely to lead anywhere. By contrast, Bohm's work and related efforts—they are hard-edged mathematical physics, after all—may very well prove extremely fruitful.

In trying to account for the Copenhagen interpretation, many suggestions have been made. However, some note might have been taken of the role of sheer ambition. It may well be that the Copenhagen School's condemnation-in-advance of any attempt to restore realism and determinism to microphysics is best explained by an insight of Francis Bacon (The New Organon, Book I, Aphorism 88): They did it "all for the miserable vainglory of having it believed that whatever has not yet been discovered and comprehended can never be discovered and comprehended hereafter."

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Atoms in Electromagnetic Fields

Claude Cohen-Tannoudji
World Scientific, River Edge, N.J., 1994. 670 pp. $53.00 pb ISBN 981-02-1243-7

Claude Cohen-Tannoudji has led in the theory of optics as applied to atomic physics over the last 30-odd years. A student of Alfred Kastler—the Nobelist inventor of optical pumping—and of Jean Brossel, his doctoral thesis spelled out the theory relevant to their school. It opened the path for Cohen-Tannoudji's "dressed atom" approach to diverse applications, culminating recently in the cooling of atomic assemblies to the micro-Kelvin range. The appearance of the present rich collection of his work constitutes an important event.

The book's format, reprints of original papers with appropriate introductions, was selected by the author—eventually—as he recalled how helpful its analogs had been to him. It implies, however, a target audience composed principally of specialists in quantum optics. The book's importance suggests that it might prove useful to a wider audience, a prospect somewhat clouded by various circumstances: Three of the book's 39 papers, originally lectures, occupy about one third of its space. Notably, over one tenth of the book remains in the original French.

Distinguishing features of the author's approach are illustrated by their contrast with Fermi's famous introduction to the quantum theory of radiation (Rev. Mod. Phys. **4**, 87, 1932). Whereas Fermi's writings and conversations reflected his assessment of the recipient's readiness to absorb his material—being thus labelled "demagogic" by a common friend—Cohen-Tannoudji's concern appears instead centered on the precision and completeness of his own material and perspective.

The development of intense laser sources through the 1960s required the initial theory of optical pumping to progress beyond its earlier, mainly perturbative, approach to that of Cohen-Tannoudji's own concept of "dressed atoms." This concept, viewing target atoms or molecules as strongly coupled to incident radiation beams, first dealt quite properly with radio-frequencies (section 2), whose intensity minimizes quantum-mechanical aspects, and later with the optical frequencies of laser beams (section 3). Consideration of multiphoton emission and of radiative corrections followed.

Later sections turn to detailed procedures designed to achieve an array of other effects: High-power lasers are used to steer the motion of atoms, whether singly or in whole ensembles. Typically, the dielectric action of a standing-wave field distorts each atom or molecule more strongly at its antinodes than at its nodes. Stimulated emission by resonant light may add to this action, thus trapping atoms or moleclues. Viewing this light–atom interaction more simply in terms of conservation of momentum, as an atom absorbs photons from a traveling wave and re-emits them in random directions, one can readily un-