leader in the construction of the CMS detector for the 14-TeV proton–proton Large Hadron Collider at CERN. Detectors such as CMS are combinations of many subdetectors, each one based on a different technology and each having a unique function. Rather than focus on the direct knowledge necessary to construct a particular system, this book examines the fundamental physics behind the interactions of particles with matter and how these interactions can be exploited to reveal some property of the particles—their mass, momentum, or energy, for example.

The Physics of Particle Detectors is full of insights and serves as a useful educational tool. (For example, the fact that nuclear cross-sections scale as the 2/3 power of the atomic number is derived geometrically.) Problems are provided at the end of each chapter; this book could be the basis of a course, in a summer school, for instance. Overviews are given of entire detector systems and a clear distinction is drawn between nondestructive (or essentially nondestructive) measurements and absorption devices that destroy the particles.

The introductory material is done rather intuitively, without rigorous derivation. This approach works, because the author freely declares his tactic and refers us to more rigorous descriptions. Specific sections differ in quality. The sections on transition radiation, magnetic fields, and electromagnetic and hadronic calorimetry are excellent. In these areas the explanations are clear and examples are provided. The basic idea that transition radiation depends on having many crossings of thin media is explained nicely. The discussions of calorimetry are particularly clear. The section on Cherenkov radiation is less well done. Distinctions, in principle, between threshold and ring-imaging devices are lost, and the sources of ring-radius error are not discussed. Several large and innovative RICH (Rich Imaging Cherenkov) systems constructed in the 1990s for the DELPHI, SLD, BABAR and CLEO III experiments are not mentioned, and the reference list is incomplete. Furthermore, some important topics are not covered: scintillating fiber tracking systems and pixel detectors, for example. However, this is to be expected in such an all-encompassing work.

The Physics of Particle Detectors is a welcome companion to other works, including volumes that give more details about specific technologies or provide more rigorous derivations. Among these other works are the companion volume in the Cambridge U. Press Series, *Particle Detectors,* by Klaus Grupen, (1996); *Techniques for Nuclear and Particle Physics Experiments*, by William R. Leo (Springer-Verlag, 1994); *Introduction to Experimental Particle Physics*, by Richard Fernow (Cambridge, U. Press, 1986); *Detectors for Particle Radiation*, by Konrad Kleinknecht (Cambridge U. Press, 1998); the more specific *Particle Detection with Drift Chambers*, by Walter Blum and Luigi Rolandi (Springer-Verlag, 1994); and *Instrumentation in High Energy Physics*, by Fabio Sauli (World Scientific, 1992). In addition, proceedings of various schools and conference series are great resources.

These include the proceedings of the ICFA (International Committee on Future Accelerators) Schools on Instrumentation in Elementary Particle Physics (World Scientific, 1988, edited by C. W. Falbjan and J. E. Pilcher; World Scientific, 1992, edited by J. C. Angus et al.; AIP Press, 1998, edited by G. Herrera Corral and M. Sosa Aquino); and AIP Press, 2000, edited by Sehban Kartal). There are also the "Beauty 1993–2000" series, published in the journal *Nuclear Instruments and Methods*, the last in volume A446 (2000), and the three conferences on Cherenkov radiation published in *Nuclear Instruments and Methods in Physics Research*: (1) "Experimental Techniques of Cherenkov Light Imaging, A343 (1994), edited by Eugenio Nappa and Thomas Ypsilantis; (2) "Techniques and Results of Cherenkov Light Imaging in High Energy Physics," A371 (1966), edited by Tord Ekelöf; and (3) "Advances in Cherenkov Light Imaging Techniques and Applications," A488 (1999), edited by Amos Breskin, Rachel Chechik, and Thomas Ypsilantis.

Sheldon L. Stone
Syracuse University
Syracuse, New York

The Feynman Integral and Feynman's Operational Calculus

Gerald W. Johnson and
Michel L. Lapidus
Oxford U. Press, New York, 2000.
$160.00 (771 pp.).
ISBN 0-19-853574-0

I have been interested in mathematical approaches to the Feynman path integral ever since I attempted in the 1950s to define functional Fourier transforms in terms of Wiener–Hermite expansions. Therefore, I was intrigued by the appearance of this monumental volume. I confess first thinking of the famous quotation by Goethe, who said, "Mathematicians are like Frenchmen: You tell them something, they translate it into their own language, and then it becomes something completely different." (This is particularly the case since both authors are mathematicians and one of them is French). I must say at the outset, however, that large parts of Gerald W. Johnson and Michel L. Lapidus's *The Feynman Integral and Feynman's Operational Calculus* are accessible to less mathematically inclined theoretical physicists, who can certainly skip some of the mathematical detail).

The idea behind the Feynman path integral goes back to a paper by P. A. M. Dirac published in 1933 in *Physikalische Zeitschrift der Sowjetunion*. It formed the core of Richard Feynman's space–time approach to quantum mechanics and quantum electrodynamics. Although the path integral was not mathematically well defined, it was widely used in quantum field theory, statistical mechanics, and string theory. Recently, path integrals have been the heuristic guide to spectacular developments in pure mathematics.

It was clear to Feynman that his "path integral" was no integral in the ordinary sense of the word, and that what he called its "summation over histories" did not involve a measure in the usual sense. Furthermore, the Lagrangian of a classical particle involves its velocity, whereas the paths over which the "integral" is extended are just continuous, not necessarily differentiable. The imaginary exponential is a highly oscillatory function, and thus most contributions cancel (except near the stationary values of the action—the classical trajectories of the particle).

In the 1920s, Norbert Wiener, extending the early work on Brownian motion by Albert Einstein and Marian Smoluchowski, introduced the notion of integration in function spaces that now goes under the name of Wiener measure, or Wiener integral. It plays a fundamental role in the theory of stochastic processes and, as distinguished from Feynman's path integral, has a rigorous mathematical underpinning. In 1947, Mark Kac realized that if one replaces the time parameter in the imaginary exponent in the Dirac–Feynman expression for the action with a purely imaginary time, the Feynman path integral becomes a Wiener integral; the Schrödinger equation (with its imaginary time-derivative) turns into the parabolic diffusion or heat equation, for which the Wiener integral provides a solution. This solution for the Schrödinger equation has become known as the Feynman–Kac formula. It has played a fundamental role in Euclidean constructive field theory and in statistical mechanics.

The book by Johnson and Lapidus deals with various approaches to making the Feynman path integral into a mathematically meaningful object. The first few chapters present a considerable amount of background material on measure theory, functional analysis, and the traditional formulation of quantum mechanics, as well as two chapters on Wiener measure and stochastic processes. This material can be particularly useful for a theoretical physicist whose mathematics may be a bit rusty.

Chapter 7 contains a detailed heuristic introduction to Feynman path integrals. It turns out that there are several independent approaches to a mathematically satisfactory definition: Edward Nelson's approach via the Lie–Trotter product formula, Kac's original analytic-continuation-in-time approach, as well as those developed by the authors, based on analytic continuation in mass and imaginary resolvents (which form the subject of later chapters). The detailed mathematical treatment is often interspersed with interesting remarks and heuristic material that eases the flow. Throughout the book one finds examples of application to problems in nonrelativistic quantum mechanics.

The second topic of this book is the Feynman operational calculus. It was invented by Feynman in 1951 in an attempt to "disentangle" exponentials of noncommuting operators such as often occur in time-ordered perturbation theory (commonly known as the Dyson time-ordered exponential). Feynman realized that his highly heuristic approach poses serious mathematical problems, and this book appears to be a first systematic, mathematically rigorous study of this subject.

The authors discuss several methods of making sense of the Feynman heuristics: via the path integral, via a "generalized Dyson series," and via a more general noncommutative calculus. These chapters may well be of interest to physicists involved in "noncommutative geometry."

The last chapter deals with other work related to the book's topics, ranging from alternative approaches to the path integral (so-called Fresnel integrals) to a very readable survey of the influence of Feynman integrals on contemporary mathematics and physics. In particular, the authors discuss low-dimensional topology and Edward Witten's approach to knot invariants, and they end with a discussion of Maxim Kontsevich's work on deformation quantization.

The list of references is quite extensive (though the acronyms, such as "GelKLLRT" are sometimes distracting, forcing the curious reader to flip back to the bibliography to find out to whom the authors refer).

I would recommend this book to serious students of the subject, if it were not for the prohibitive price; let's hope that the publishers will release a more reasonably priced paperback, accessible to graduate students and emerit(ae)i.

Meinhard E. Mayer
University of California, Irvine

The Charm of Strange Quarks: Mysteries and Revolutions of Particle Physics

R. Michael Barnett, Henry Mühry, and Helen R. Quinn
Springer-Verlag, New York, 2000. $39.95 (302 pp.). ISBN 0-387-98897-1

Despite the intense research that has been done in particle physics, the public remains mostly mystified by the subject. The field's conceptual and mathematical complexity is a barrier even to individuals who are interested in particle physics but lack the skills necessary to unravel its mysteries.

We rely on K–12 education to provide citizens with the foundations of science that will enable them to understand new scientific developments. Yet physics courses at the high-school and even introductory-college levels are preoccupied with classical physics; little time is left for 20th-century physics. Most high-school physics curricula, even the *National Science Education Standards* (National Academy Press, 1996), do not move past atomic structure and radioactive decay, the physics of the 1930s. Until recently, textbooks included little, if any, discussion of elementary particles.

The preface to *The Charm of Strange Quarks* contains a clear statement of intent "to bring the excitement and a basic understanding of this fundamental topic to the public and especially to students." In the first two-thirds of the book, the authors present the Standard Model of particle physics and related elements of cosmology. Concepts and discoveries, starting with the structure of the atom, are emphasized. Although it feels like a traditional text, this book has no questions or problem sets at the end of the chapters. Using few equations, the authors augment the main text with drawings, photographs, and boxed inserts, providing concise physics explanations or recognition of the contributors to this work. The emphasis on the work of scientists is an important feature, with the first chapter dedicated to the story of the independent discoveries of the J/ψ particle by physicists working at SLAC and at Brookhaven National Laboratory.

While the mathematical complexity is absent, the book is not "light" reading. The language is sufficiently technical that a solid understanding of basic physics is essential. The history of the discoveries is presented in a coherent fashion, with clear and thorough explanations of the significance or surprise that each contributed. The interdependence of experimental and theoretical physics is accurately portrayed, with examples where each breaks new ground. The reader will be convinced that the Standard Model is not a far-fetched theory but an established framework grounded in both mathematical reasoning and experimental verification. Not only is the Standard Model well explained, but its limitations, such as its inability to predict quark masses or to unify strong and electroweak forces, are clearly stated. The relevance of particle physics to cosmological issues, and new theories addressing unresolved questions, are explored (in chapters 8 and 9) in fascinating yet readily comprehensible terms.

Although it is a thorough presentation, *The Charm of Strange Quarks* appears disjointed in some places, especially in chapter 3 in which flavors of quarks, discussed on page 52, are reintroduced on page 62 as if they had not been discussed previously. At times, the explanations are too short and would benefit from additional elaboration, as in the case of the explanation of quark masses on page 68. The book includes a few real-world analogies to help visualize difficult concepts, such as exchange of virtual particles during an interaction. Additional analogies would be useful.