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The genesis of Feynman diagrams. (English) Zbl 1226.81008

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Feynman diagrams enable us to find the relevant expressions in a perturbative expansion to the equations describing the dynamics of a quantum electrodynamic system. From the very conception of the process as a sequence of particle creations and annihilations, one can draw a scheme relating these creations and annihilation events. The diagram thus obtained can then be transmogrified, element by element, into a complex mathematical expression, the evaluation of which yields an observable quantity characterizing the physical system. The aim of this book is to reconstruct the route that led Feynman, between approximately 1946 and 1948, to devise his new methods of diagrams and to evaluate what was achieved.

The book consists of 7 chapters. The core of the book are Chapters 2–6. In Chapter 2 the author discusses the diagrams used by *H. Euler* [Ann. der Physik, V. F. 26, 398–448 (1936; Zbl 0014.23706)] and by Ziro Koba and Gyo Takeda in the latter half of the 1940s as precurssors of diagrammatic representations. By doing so, he discerns the change in the conception and representation of diagrammatic representations brought out by Feynman and Dyson.

Chapter 3 is concerned with Feynman's PhD thesis. In the early 1940s, when Feynman was a graduate student, one of the most pressing problems in theoretical physics was the fact that infinite quantities arose from some of the principles of electrodynamics in both classical and any attempted quantum theory. Feynman's strategy was first to establish a divergence-free classical electrodynamics and then to quantize it. *R. P. Feynman* and his supervisor *J. A. Wheeler* [Rev. Mod. Phys. 21, 425–433 (1949; Zbl 0034.27801)] had already developed an alternative theory of classical electrodynamics with the desired feature that awaited quantization by the time Feynman had started working on his thesis.

The standard procedure for quantizing a classical theory was to interpret the classical Hamiltonian function as an operator in a Hilbert space of standard vectors. The problem with quantizing the Wheeler-Feynman theory of electrodynamics was that it could not be formulated by specifying a Hamiltonian function. Therefore Feynman needed a method to quantize physical systems whose classical descriptions could not be given by Hamiltonian functions. Feynman based his quantization procedure on Paul Dirac's considerations on how to construct a quantum theory out of the Lagrangian formulation of classical mechanics, though the story was not so direct. To Feynman with some misunderstanding, Dirac appeared rather vague about the exact nature of the relationship between the exponential $e^{\frac{iL\delta t}{\hbar}}$ of the Lagrangian function L and the function $(q_{t+\delta t}|q_t)$ that related the state descriptions in terms of the coordinates at two different times in an infinitesimal distance. To have a relationship between the wave functions at two times infinitesimally close did not, however, solve Feynman's original problems, which undoubtedly included calculating the probability of transitions from one state at time t_0 to another state at a later time T with no restrictions on the difference $T - t_0$. Feynman constructed wave functions inductively by dividing the interval $[t_0, T]$ into a very large number of infinitesimal intervals. It was expected that, in the limit of infinitesimally small intervals, the appropriate relationship would turn into an equality and the sum in the exponential could be replaced with an appropriate integral. The problem is where integrations over infinitely many variables, infinitely close to each other, should be performed. Neither Feynman nor anybody else so far has been able to define such a procedure precisely and to justify rigorously the sum with an integration. Feynman did not consider himself to be in a position to answer the difficult mathematical questions as to the conditions under which the limiting process of subdividing the time scale actually converges. He was satisfied to give a qualitative description of the limiting process and to point out the similarity between the sum in the exponential and a definition of the corresponding integral. The results of Feynman's thesis were non-relativistic throughout.

Chapter 4 is concerned with Feynman's great struggle to look for a physical system, the appropriate description of which would satisfy the Dirac equation. Feynman recognized that the quivering feature of the electron would fit the extension of his alternative formulation to relativistic systems perfectly by finding that the mainly relevant paths were of a type familiar in the study of Brownian motion. The author shows in Chapters 4 and 5 that the first Feynman diagrams (i.e., before Dyson's intervention) are a product of Feynman's efforts to understand the Dirac equation not just in a mathematical way. Feynman's aim was to describe Dirac's well-known theory in alternative ways. Feynman believed that the equations had to be completed by pictures, and several pictures were possible for the same equations. He tried to interpret the known equations in such a way that it became clear which assumption in the theory was causing the inconsistent conclusions in the troublesome cases. *R. P. Feynman*'s alternative theory appeared in [Phys. Rev., II. Ser. 76, 749–759 (1949; Zbl 0037.12406); Phys. Rev., II. Ser. 76, 769–789 (1949; Zbl 0038.13302)].

Chapter 6 deals with Dyson's elaboration of Feynman diagrams. Feynman gave the first public presentation of his alternative formulation of quantum electrodynamics (QED) at a conference on physics sponsored by the National Academy of Sciences and held at Pocono Manor, Pennsylvania, during March 30 and April 1, 1948. It was a complete disaster, for the audience failed to understand how Feynman could possibly justify his results, even though admitting that the derived results were perfectly correct. In [Phys. Rev., II. Ser. 75, 486–502 (1949; Zbl 0032.23702)], *F. J. Dyson*, being familiar with the more conventional method of second quantization, showed that the three theories of R. P. Feynman, *J. Schwinger* [Phys. Rev., II. Ser. 74, 1439–1461 (1948; Zbl 0032.09404)] and Japanese physicists *S. Tomonaga* [Prog. Theor. Phys. 1, 27–42 (1946; Zbl 0038.13101)] and *Z. Koba, T. Tati* and *S. Tomonaga* [Prog. Theor. Phys. 2, 101–116, 198–208 (1947; Zbl 0038.13102)] to remove QED's uninterpretable divergences were equivalent. In [Phys. Rev., II. Ser. 75, 1736–1755 (1949; Zbl 0033.14201)], *F. J. Dyson* extended his systematization of Feynman's methods to include the treatment of problems with several particles in the initial and final states, instead of only one as in the previous paper. Herein Dyson presented Feynman's theory as an S-matrix theory in the tradition of *W. Heisenberg* [Z. Phys. 120, 513–538 (1943; Zbl 0028.27901); Z. Phys. 120, 673–702 (1943; Zbl 0028.27902)]. The author remarks that Dyson introduced a new equivalence relation among graphs, which enabled him to present the algorithm for evaluating matrix elements more effectively and allowed for fewer redundancies in the diagrams' articulation of the phenomena.

The book is highly readable for physicists as well as for philosophers of physics and physics-oriented mathematicians.

Reviewer: Hirokazu Nishimura (Tsukuba)

MSC:

81-03 Historical (quantum theory)
01A60 Mathematics in the 20th century
81T18 Feynman diagrams
81Q30 Feynman integrals and graphs; applications of algebraic topology and algebraic geometry
81U20 S-matrix theory, etc. (quantum theory)
81V10 Electromagnetic interaction; quantum electrodynamics
81Q05 Closed and approximate solutions to quantum-mechanical equations

Keywords:

Feynman diagram; second quantization; quantum field theory; quantum electrodynamics; S-matrix theory; Dirac equation; Schrödinger equation

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