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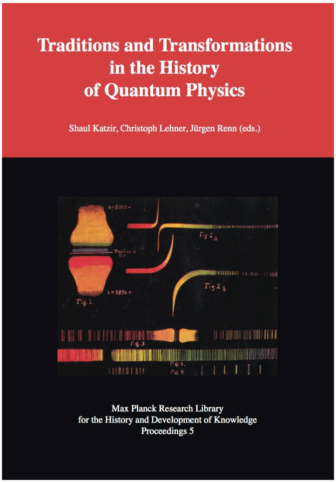
Shaul Katzir, Christoph Lehner and Jürgen Renn:

Introduction



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Introduction

The present volume presents results of recent research into the history of quantum physics. The thirteen papers included here show the multifaceted nature of this research. They discuss developments from the late nineteenth to the early twenty first century and go beyond the traditional focus on Europe and North America to include China and Japan. Also a wider array of subdisciplines comes into view, from optics to quantum gravity through quantum electrodynamics, from atomic and nuclear to condensed matter physics and the foundations of physics. The perspective of the papers ranges from local histories to global discussions, from conceptual changes driven by experimental practices to interactions of the new theoretical physics with social and technological forces.

Several novel aspects of the history of quantum physics emerge in these contributions. Actors who have so far played only a marginal role in the historical account, such as Otto Sackur, Maria Göppert and Chang Tsung Sui,[1] are now recognized for their roles in the development of quantum physics. Similarly, fields such as dispersion theory, physical chemistry and solid state physics receive a more prominent place in the narrative of its development. In this historical perspective, they no longer constitute just areas of applications but are seen as birthplaces of important theoretical insights. Developments off the main road of the traditional narrative, such as the pursuit of the idea of light molecules or early explorations of the relations between the quantum and gravity, constitute another focal point of this volume. This collection also makes clear that recent research rightly pays increasing attention to the role of modeling and representation in the formation of quantum theories.

Despite the diversity of the themes treated, one common thread emerges: the importance of continuities in the historical development of quantum physics. The place of long established traditions can be seen, for example, in the role that traditional modes of experimental physics, associated with the nineteenth century, continued to play in developing new theoretical ideas, including those associated with the quantum hypothesis. The case of optical dispersion shows that even after the introduction of Niels Bohr's atomic model physicists continued to suggest theories of dispersion based on late nineteenth century atomistic models, and that the problem of harmonizing these theories with the developing quantum theory

[1] In this introduction we use the traditional order for Chinese and Japanese names.

led to central theoretical insights. Further continuity can be discerned in the persistent role of trans-disciplinary fields such as physical chemistry or nanoscience in generating conceptual and methodological innovations, as well as in linking science and technology.

The first section of the volume deals with the transition "From Classical to Quantum Physics." This transition is often associated with the notion that certain crucial experiments refuted tenets of classical physics and necessitated the introduction of revolutionary new theories. This transition is also often associated with the emergence of theoretical physics as an independent subdiscipline and with a new division of labor between theoreticians and experimentalists. Here it is shown, however, that the connection between empirical knowledge, experiments, and theoretical reasoning was much more complex, characterized by an overlap between classical and quantum ideas and also by a less strict division of labor than has traditionally been assumed.

In earlier periods of physics, experiments were often not tied to well-defined quantitative theoretical claims but were of a merely qualitative nature. In his contribution, Shaul Katzir shows that more qualitative, exploratory experiments of this kind, not directly guided by the intention to systematically check quantitative implications of mathematically formulated theories, did play a crucial role in the early history of quantum physics and possibly beyond.

Marta Jordi studies the crucial role of empirical knowledge, embodied in established theories of classical physics, for the emergence of the new quantum physics. She shows, in particular, how knowledge of the well-developed classical theory of dispersion was represented in the model of co-vibration of matter and light that not only survived the transition to quantum physics but also helped to shape its conceptual foundation.

The early history of quantum physics was marked by a rapid growth of the number of phenomena to which some form of quantum hypothesis was applied. Ever expanding domains of radiation and thermal physics were touched by quantum theory. How did this expansion of the quantum happen? It did not, at least initially, take place as part of a systematic research program. Rather, it occurred because existing and sometimes long-standing problems such as that of chemical equilibrium could be connected to the quantum. Moreover the transfer of the quantum hypothesis to new areas of application was not necessarily achieved by its most famous protagonists, but often by scientists simply looking for new tools to solve such long-standing problems. One such scientist was the physical chemist Otto Sackur whose contribution to the quantum theory of gases is analyzed in the paper by Massimiliano Badino and Bretislav Friedrich. They show that his pragmatic and goal-oriented attempt to address a long-standing problem of physical chemistry—how to calculate the chemical constants defining equilibria in chemical reactions—led to a novel and significant use of the quantum hypothesis in the theory of the ideal gas.

As the quantum hypothesis was extended to new domains, it continued to raise conceptual problems, which are the focus of the second section. Albert Einstein's introduction of the light quantum in 1905 remained controversial for at least twenty years. Debates over the nature of radiation accompanied the further development of quantum physics and often suggested innovative ideas such as the idea of considering a wave-particle duality for matter as well, or introducing a new statistics. These debates also involved ideas that, at the time, represented serious candidates for an understanding of the nature of light, but that were later dismissed and even forgotten. One such idea was the idea of light molecules introduced by Mieczysław Wolfke in 1921 and developed further by Walther Bothe, especially in an unpublished manuscript from 1925, analyzed for the first time in the contribution by Dieter Fick and Horst Kant to this volume.

The idea of light molecules was superseded by the introduction of a new statistics to radiation theory by Satyendra Nath Bose and to gases by Einstein. In her contribution, Daniela Monaldi discusses the emergence of the new statistics and its relation to early work on many-particle systems by Werner Heisenberg and Paul Dirac. She shows, in particular, that the revolutionary potential of the new statistics for developing physicist's understanding of the concept of a particle and of a physical system was not realized in their works. Instead, both Heisenberg and Dirac, in spite of the great differences between their works, stuck to a classical understanding of individual particles and their statistical independence.

Today, quantum physics and gravitation theory are two clearly separate domains whose integration is considered to be one of the most challenging conceptual problems of modern physics. In his contribution Dean Rickles shows that the need to unify them was evident to some physicists as early as the 1910s, that is, well before the formulation of either general relativity or quantum mechanics. Thus, many ideas still under discussion currently, such as the existence of more than four dimensions of space and time or the existence of a new physics at the scale of the Planck length, were broached even then. Back then, however, it was still an open question whether such ideas would actually be needed in order to complete the building of quantum theory and of general relativity, or whether this could be achieved without establishing a bridge between them.

The section "Extending the Framework of Quantum Physics" deals with examples of contributions to the expanding field of quantum mechanics after its firm establishment in the mid-1920s. This involved scientists who brought quite diverse intellectual backgrounds to the bourgeoning field. The period is explored in three papers that stress the importance of these different disciplinary backgrounds and local traditions.

Ito Kenji analyzes the educational background of Nishina Yoshio, one of the leading Japanese physicists of the first half of the twentieth century. In 1928, together with Oskar Klein, Nishina developed the so-called Klein-Nishina formula describing the scattering of light quanta and electrons based on the relativistic Dirac equation for the electron. Ito makes it clear that the introduction into Japan of Western science and technology in the late nineteenth century enabled Japanese scientists of Nishina's generation to become important contributors to quantum theory, on a par with their Western colleagues. He shows, in particular, that advanced training in electrical engineering could provide an advantageous starting point for such careers.

Barry Masters takes us to one of the centers of quantum physics—Göttingen circa 1930—to explore the context and origin of Maria Göppert's dissertation on atomic transitions involving two photons (as opposed to the simple one-photon processes that Dirac had treated in his groundbreaking paper on the quantum theory of emission and absorption of radiation in 1927). Masters shows how Göppert's work is rooted in Dirac's paper and in the work of Göttingen physicists Otto Oldenberg and James Franck, who studied more complicated interactions between radiation and matter both experimentally and theoretically. The story reminds us of the importance of new applications for the establishment of a theory such as Dirac's and for its extension and corroboration despite severe internal difficulties.

Roger Stuewer describes the two distinct traditions of nuclear physics that merged when Lise Meitner and Otto Frisch puzzled out an interpretation of Fritz Straßmann and Otto Hahn's findings of unexpected elements in the decay of uranium after bombardment with neutrons. Meitner, coming from Berlin, was familiar with the work of Heisenberg and Carl Friedrich von Weizsäcker on Gamow's liquid-drop model of the nucleus. On the other hand, Frisch had been working in Copenhagen on Bohr's theory of the compound nucleus. The combination of the detailed energetic implications of the Berlin model and the dynamical emphasis of the Copenhagen approach resulted in a theoretical discovery of great consequence, nuclear fission.

The section "The Challenges of Quantum Field Theory" explores physicists' struggles to formulate a consistent quantum theory of fields by building on the early successes of Dirac's and Pascual Jordan's quantum electrodynamics. Despite these successes, it had quickly become clear that quantizing the electromagnetic field led to a set of difficulties that threatened to make the procedure meaningless. From the late 1920s until the success of the renormalization program in the late 1940s, theorists were trying to find a firmer theoretical basis for quantum electrodynamics.

The paper by Yin Xiaodong, Zhu Zhongyuan and Donald Salisbury deals with work of the Chinese physicist Chang Tsung Sui on one such theoretical difficulty of quantum electrodynamics. The problem was one encountered by Heisenberg and Wolfgang Pauli in 1928/29 in their first attempt to formulate a general theory of quantum electrodynamics. Quantizing the electromagnetic field using canonical quantization, which derives the commutation equations of a quantum theory from the Hamiltonian formulation of the corresponding classical theory, led to ambiguities. These appear in the quantization of all theories that, like electrodynamics, involve a gauge freedom, i.e. degrees of freedom in the theoretical quantities that do not have a physical meaning. Chang had visited Cambridge twice in the 1930s and 1940s. Inspired by Dirac, he wrote several papers addressing the question of how to quantize such theories. These papers anticipate results of better known works by Dirac and by James Anderson and Peter Bergmann in the 1950s.

Adrian Wüthrich's contribution is concerned with the development of Feynman diagrams, which was closely connected to another foundational difficulty of quantum electrodynamics, the infinite values predicted by the theory for most physical quantities due to its treatment of the interaction between radiation and matter. Wüthrich argues that it was Richard Feynman's attempt to find a physical interpretation of the Dirac equation in terms of the motion of a particle that led him to designing diagrams in terms of the propagation of quanta. While Feynman eventually had to abandon this interpretation, the diagrams remained as a powerful calculational tool. They now represented merely certain expressions in a calculation without presupposing that the particle actually travels along definite trajectories. It was in this sense that Freeman Dyson used Feynman diagrams to show that the infinite expressions in quantum electrodynamics could be redefined such that they only affected non-observable quantities.

In the last section "Traditions and Debates in Recent Quantum Physics," Olival Freire and Christian Kehrt examine very different aspects of recent developments within quantum physics, from its philosophical interpretation to its technological applications. Freire analyzes the view, influential in contemporary debates about the interpretation of quantum mechanics, that the consistent history approach has inherited the Copenhagen interpretation's role in the interpretation debate and has become a "new orthodoxy." Freire shows, on the basis of bibliographical data, that this view does not stand empirical scrutiny.

Based on a case study of a local research network in Munich, Kehrt argues that the emergence of the trans-disciplinary field of nanotechnology opened up new research directions for solid state physicists, in particular through the adaptation of methods from the life sciences, as well as new funding sources, entrepreneurial opportunities, and resources for public presentations. Following

Paul Forman, he sees this development as characteristic of the sciences at the turn to the twenty-first century, in the sense that technology takes primacy over science.

The present volume originated from the Third International Conference on the History of Quantum Physics (HQ-3), which took place in Berlin in summer 2010 and included speakers from five continents. The conference series was launched by the joint project on the history of quantum physics of the Max Planck Institute for the History of Science and the Fritz Haber Institute of the Max Planck Society.

We would like to thank all participants in the conference and reviewers of the papers that appear here for their helpful advice. Special thanks to Nina Ruge and her editing team: Heidi Henrickson, Oksana Kuruts, Jonathan Ludwig and Marius Schneider for ensuring that this book materialized. And thanks to our colleagues Christian Joas, Jeremiah James and Alexander Blum for their help in many ways. Lastly we are happy to acknowledge the Strategic Innovation Fund of the President of the Max Planck Society, which supported the history of quantum physics project.