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Book Review

The Theory of Open Quantum Systems. By H.-P. Breuer and F. Petruccione. Oxford University Press, New York, New York, 2002, xxi + 625 pp., $55.00 (hardcover). ISBN 0-19-852063-8.

The study of open systems, irrespective of whether openness arises due to the mostly inevitable interaction with some environment or due to the coupling with a suitably chosen measurement apparatus, has recently been and still continues to be a relevant part of the research work focusing on quantum mechanics. Not only it has contributed to the development of new physical insights and techniques, but it has also put to work a more modern formulation of quantum mechanics, mainly arisen as a result of physical and mathematical foundational studies on the statistical structure of quantum theory. Not by chance the book opens with two introductory chapters dealing with classical probability theory and stochastic processes on one side, quantum probability and a formulation of the theory of quantum measurement in terms of effects and operations on the other side, doing justice to both aspects. One of the main reached aims of the book is in fact to show, with the sound attitude of a working theoretical physicist paying great attention to concrete experimental realizations, the deep and fruitful relationship between the description of the dynamics of an open system, possibly undergoing some indirect measurement, and the notion of classical stochastic process. The relevance of these ideas also appears in a recent publication by Holevo (A. S. Holevo, *Statistical Structure of Quantum Theory*, Springer, 2001), which briefly presents, in a deep and mathematically rigorous way, the full-fledged structure of the modern formulation of quantum mechanics, ranging from the notion of operation and effect, dating back to Ludwig's work, to instrument and positive operator valued measure.

This book by Breuer and Petruccione is very clearly written and essentially self-contained. All the results are obtained providing the reader with the main steps of the calculation, so that he can actually follow, and lots of examples and applications are worked out in detail, often supporting the results with the aid of numerical studies and graphical representations. The amount and variety of fields of applications, techniques and examples, often directly connected to the author's own research work and reflecting their expertise, distinguish this book from other publications on the subject. The reader is nevertheless greatly helped by the detailed logical subdivision of the work in parts, chapters and smaller units.

The first introductory chapter presents in a concise way the basic concepts of classical probability and stochastic processes. This physically minded presentation provides the reader in particular with the notion of piecewise deterministic process and Lévy process, not so easily obtained reading an introductory presentation, which play a central role, the former in the unravelling of master-equations, the latter in the study of sub-recoil laser cooling of atoms (see also F. Bardou *et al.*, *Lévy Statistics and Laser Cooling*, Cambridge University Press, 2001). The second chapter stresses the peculiar features of quantum probability versus classical probability, a hardly won but most relevant concept (see also R. Alicki and M. Fannes, *Quantum Dynamical Systems*, Oxford University Press, 2001). A modern version of quantum measurement theory is presented, stressing the relevance of probability concepts and presenting the key notions of effect and operation, together with simple examples. Only these new tools, going beyond the too stiff and idealized scheme of projection and ideal von Neumann measurement, allow for the development of the presented comprehensive theory of open quantum systems.

Part two presents the quantum counterpart of classical Markov processes, i.e., quantum dynamical semigroups, together with the associated Lindblad type master-equations. The main types of Markovian master-equation are derived and treated in detail, stressing their limits of validity. The Caldeira–Leggett model and its exact treatment beyond the high temperature Markov approximation is also considered. In a separated chapter the phenomenon of decoherence is dealt with, also thoroughly discussing the recent experiment on the decoherence of mesoscopic superpositions of coherent field states in a cavity. The chapter ends with a discussion of how decoherence does not provide a solution to the measurement problem, contrary to what is sometimes believed, despite the fact that any system or apparatus is obviously never perfectly isolated from the environment.

In part three the authors first introduce the central concept of selective versus non selective measurement. In the spirit of their own research work, they then proceed to introduce the notion of stochastic process in Hilbert space in terms of probability density functionals on Hilbert space, related to a particular selective measurement. The covariance matrix of the probability density functional gives a statistical operator evolving according to the master-equation. This leads to the so-called unravelling of the master-equation, describing the dynamics of the open system in terms of a stochastic process for the wave function, typically given by a piecewise deterministic process, with a deterministic evolution interrupted by quantum jumps. The non-uniqueness and physical meaning of these unravellings are understood thanks to the theory of continuous measurement. A further chapter is devoted to features and advantages of the stochastic simulation method, while the last one deals with many interesting applications to quantum optical systems, including the most recent topics of dark state resonances and sub-recoil laser cooling.

The fourth part is devoted to a study of non-Markovian effects exploiting the time-convolutionless projection operation, which leads to a systematic perturbation expansion given by time-local master-equations. The advantages and versatility of this method are shown by means of different applications, involving numerical calculation and comparisons with exact results.

The last part of the book, concerning relativistic quantum processes, contains a great deal of original work, and appears as most promising for future extensions. The first chapter deals with the extension of the quantum theory of measurement to the relativistic framework. In this perspective the Schwinger–Tomonaga formalism, where states appear as functionals of spacelike hyper surf aces, acquires a deeper meaning. A covariant formulation of state reduction is given, taking place along the spacelike hypersurfaces crossing the classical event given by the result of a local measurement. One can however not only consider local measurements, but also non-local ones obtained through entangled probes. In this framework the microcausality principle leads to severe restrictions on the measurability of states and observables. A clear and satisfactory discussion of the compatibility of the causality principle with quantum teleportation is given. The very last chapter addresses the question of describing a physical system in terms of quantum field theory, not restricted, as it is often the case, to a scattering framework. The precise aim is the description of the reduced statistical operator associated to matter interacting with the quantized electromagnetic field. This is obtained by combining functional methods and superoperator techniques, i.e., the use of mappings acting on spaces of operators, which prove very powerful and elegant, leading to a superoperator representation for the influence functional of QED. As a specific application decoherence of a charged particle due to Bremsstrahlung is considered. First steps in the direction of the understanding of renormalization are done, showing how natural cutoffs arise due to the finite preparation time of any real experiment: a road which is certainly worth pursuing further.

This brief résumé does not exhaust the full inventory of mathematical techniques and physical applications considered in the book, but rather shows, biased by the writer's understanding and interests, the main highlights of the publication. The plain and clear style of the book make it accessible to a wide audience, only asking for some basic knowledge of quantum mechanics, also thanks to the rich and well-organized table of contents. It is however not only a very good and thorough introduction to the subject, but also a precious reference for researchers well-acquainted with some specific field inside the theory of open quantum systems, willing to enlarge their horizons or follow the new stimuli given by the authors.

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