

Preface

Theoretical physics evolved from Newton's mechanics to a general theory for modeling dynamical systems. Theoretical physicists not only earn their income by investigating traditional physical systems like particles, condensed matter and star systems, but also by applying their modeling skills on economics, informatics, medicine, psychology, biology, environment, climate, language and sociology. This is to a substantial part caused by a very flexible toolbox theoretical physicists learn to use. It is this toolbox which makes physics a science with strong impact on man and nature. This book is about the organization of this toolbox. Though, it is intended as a little entertaining piece of natural philosophy and not as a nosh for the military-industrial complex.

The central aim of this book is to present Markov and quantum processes as two sides of a coin called generated stochastic processes. Quantum processes are reversible stochastic processes generated by one-step unitary operators while Markov processes are irreversible stochastic processes generated by one-step stochastic operators. The characteristic features of quantum processes are oscillations, interference, lots of stationary states in bounded systems and possible asymptotic stationary scattering states in open systems, while the characteristic features of Markov processes are relaxations to a single stationary state. Quantum processes apply to systems where all variables that control reversibility are taken as relevant variables, while Markov processes emerge when some of those variables cannot be followed and are thus irrelevant for the dynamic description. Their absence renders the dynamic irreversible. Once one realizes that Markov processes are incapable to describe reversibility, a necessity for the description of reversible stochastic processes arises and abstract quantum theory does this job in close analogy as Newton mechanics does the job for deterministic processes. Newton's invention as compared to Aristotle's view was the introduction of two properties serving as initial condition. The initial coordinate plus the initial velocity are needed to formulate deterministic reversible processes. Similarly, for stochastic processes not only the initial probability density defines the state (as in Markov processes), but also the probability current density specifies the state in order to define

reversible stochastic processes. Both quantities must be independent except for the probability conservation. By generating probability density and current density from a two component pre-probability,¹ unitary quantum theory reaches this goal in a most elegant and compact way. In that sense the pre-probability as a complex wave function does have a very clear and—to me—intuitive physical interpretation: its squared modulus is the positive probability density and its phase generates the probability current density as the two components of a state for a reversible stochastic process. A similar more mathematically oriented reconstruction of quantum theory as a theory for reversible stochastic processes was formulated by Hardy in 2001.²

A further aim is to demonstrate that almost any subdiscipline of theoretical physics can conceptually be put in the context of generated stochastic processes. Classical mechanics and classical field theory are about deterministic processes which emerge when fluctuations in relevant variables are negligible. Quantum mechanics and quantum field theory are about genuine quantum processes. Equilibrium and non-equilibrium statistics apply to the regime where relaxing Markov processes emerge from quantum processes by omission of a large number of uncontrollable variables. Systems with many variables often self-organize such that only few slow variables can serve as relevant variables. Symmetries and topological classes are essential in identifying such relevant variables.

The third aim is to provide conceptually general methods of solutions which can serve as starting points to find relevant variables as well as to apply best practice approximation methods. Such methods are available through generating functionals.

The potential reader is a graduate student who likes to learn about quantum systems from few to many particles and about stochastic processes in a unifying way. She or he has heard already a course in quantum theory and equilibrium statistical physics including the mathematics of spectral analysis (eigenvalues, eigenvectors and Fourier and Laplace transformations) and may also have had some contact to the particle number representation of many body systems. The book does not follow the standard route of the present day's theoretical physics education³ and does not focus on one particular subject of such education. The reader should be open for a unifying look on several topics. If she or he then likes to be educated in one particular subject like condensed matter theory or particle physics or Markov processes in many of their facets, she or he may consult the texts cited in the book at appropriate points.

¹A notion lend from R.B. Griffiths: Consistent Quantum Theory, Cambridge University Press, 2002.

²L. Hardy: Quantum Theory From Five Reasonable Axioms, [arXiv:quant-ph/0101012v4](https://arxiv.org/abs/quant-ph/0101012v4).

³See however the lecture notes of J. Chalker and A. Lukas, where quantum processes and Markov processes are discussed together: J. Chalker, A. Lukas: Lecture Notes on M. Phys Option in Theoretical Physics: C6, <http://www-thphys.physics.ox.ac.uk/people/JohnChalker/theory/lecture-notes.pdf>.

I was first impressed by the richness of Markov processes by a lecture in 1987 of my teacher János Hajdu and later in the 1990s by the applications in original research by my teachers John Chalker and Boris Shapiro. I came to apply them in my own work and gave a lecture course in 1998 based on these experiences. I became aware that the Chapman–Kolmogorov equation is very similar to the unitary time evolution in quantum theory and found a remark in a book of C.F. von Weizsäcker⁴ which I interpret in the following way: quantum theory does not formulate a new probability theory but only a new dynamics for probabilities as compared to the Chapman–Kolmogorov dynamics. I liked to elaborate on this idea and so the original plan of writing a book on Markov processes evolved over more than 10 years into its present state.

I like to thank Claus Ascheron from Springer for his patience and encouragement to finally transform my collection of lecture notes into a book. I also wish to thank János Hajdu for his long-lasting intellectual and emotional support and for many enlightening discussions over these years. Big thanks the students of my courses who helped very much to shape the final content. Special thanks go to Stefan Brackertz and Patrick Sudowe for intensive discussions about notions and interpretations. Finally, I thank my father, Theo Dores Janssen, for having confidence in me and for initiating my desire to clean up the desk.

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⁴C.F. von Weizsäcker: *Aufbau der Physik*, dtv, pp. 309–310, 1988.

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