Preface

This book arose from a lecture course on open quantum systems that I had the chance to teach at the Technical University of Berlin. I was asked to give a lecture on my research for an audience that was composed of graduate students specializing in very different areas of physics. Consequently, I had to start with an introduction that generated a common ground. In order to give all students an opportunity to treat hot research topics, I decided not to teach overly sophisticated technical tools. Instead, I tried to make the lecture as self-contained as possible and—with some work involved—straightforward to follow. Presenting that lecture was a fun adventure for me: I had to put my research results into a somewhat wider background and rethink exactly which points were the most important to make. Soon after the actual lecture, I was asked to provide a lecture script for later reference, which triggered the idea for this book.

During the writing of this book, as the research advanced, so did the book; thus, it now contains a few more topics than were treated in the original lecture. However, keeping the original motivation, it aims at providing graduate students or researchers with a little background in quantum theory—what one typically learns during two semesters of quantum theory—with a straight route to the dynamics of open quantum systems. This route is not necessarily easy, since the readers might have to invest some work if they are unfamiliar with certain techniques or topics. Neither can it be claimed to be the only path, and the readers are certainly invited to find and explore possibly simpler or more elegant pathways.

In my opinion, the road to open quantum systems is a very rewarding journey: New decades bring new challenges, and one of the challenges of our decade certainly is to understand and control the behavior of the smallest systems. Just as the steam engine led to the industrial revolution, one can anticipate that nanomachines will not just be useful in existing applications (e.g., drug design and delivery, microfabrication, and DNA construction). Beyond this, they may also yield an unimaginable number of new applications. Nanomachines cannot be described by thermal equilibrium. Therefore, it seems a rewarding enterprise to understand the evolution of open quantum systems when coupled to non-equilibrium reservoirs.

In this book, we will provide several possibilities to treat such non-equilibrium reservoirs. The simplest idea is to compose a non-equilibrium reservoir from subsystems that are held at different equilibrium states. This approach can only be well motivated in the weak coupling limit. Then, quantum master equations have many favorable properties: These properties enable one to interpret the dynamics of quantum systems coupled to different equilibrium reservoirs similarly to the dynamics of heat engines. Alternatively, we can study strongly coupled quantum systems that—when scaled up in size to the thermodynamic limit with an infinite recurrence time—may assume a non-equilibrium stationary state. Beyond this, there are many more examples of non-equilibrium systems to study. In this book, we will also treat systems subject to external driving and systems that are continuously monitored and controlled, which includes feedback control.

On the technical side, the book provides concepts useful in the presence of the aforementioned situations: multiple reservoirs, non-equilibrium reservoirs, additional monitoring, and feedback control. These methods include master equations, the extraction of full counting statistics from these equations, thermodynamic interpretation of master equations, and of course methods for their solution. It is further demonstrated how the conventional weak coupling limit can be overcome in some cases and how true non-equilibrium reservoirs alter the dynamics. The book contains a number of exercises of varying difficulty, which the reader is invited to solve. The solutions to the exercises are not part of the book, but can be downloaded from the on-line supplement (http://extras.springer.com/ZIP/2014/978-3-319-03877-3.zip). Corrections and suggestions for improvement should be addressed to me:

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The examples in this contribution have mostly originated from my own research and that of collaborators and students, to whom I would like to express my deepest gratitude. Tobias Brandes, Clive Emary, Massimiliano Esposito, Gerold Kießlich, Thilo Krause, Philipp Strasberg, Christian Nietner, Gabriel Topp, and Malte Vogl have—among many others to whom I apologize for not mentioning them—questioned my views and sharpened my thinking. Without these wonderful people, this book would not have been possible. Any errors are, of course, entirely my own.

Finally, I would like to apologize to my wife and my little daughters for being a distracted husband and father during the writing of this book. After all, it is the joy you bring that keeps me going.

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