Preface

To write an introduction to the dynamics of open quantum systems may seem at first a complicated, albeit perhaps unnecessary, task. On the one hand, the field is quite broad and encompasses many different topics which are covered by several books and reviews [1–36]. On the other hand, the approach taken to study the dynamics of an open quantum system can be quite different depending of the specific system being analyzed; for instance, references in quantum optics (e.g. [1, 10, 11, 15, 17, 26]) use tools and approximations which are usually quite different from the studies focused on condensed matter or open systems of relevance in chemical physics (e.g. [8, 13, 27, 30, 33]). Moreover, very rigorous studies by the mathematical physics community were carried out in the 1970s, usually from a statistical physics point of view. More recently, and mainly motivated by the development of quantum information science, there has been a strong revival in the study of open many body systems aimed at further understanding the impact of decoherence phenomena on quantum information protocols [53].

This plethora of results and approaches can be quite confusing to novices in the field. Even within the more experienced scientists, discussions on fundamental properties (e.g. the concept of Markovianity) have often proven not to be straightforward when researches from different communities are involved.

Our motivation in writing this work has been to try to put black on white the results of several thoughts and discussions on this topic with scientists of different backgrounds during the last three years, as well as putting several concepts in the context of modern developments in the field. Given the extension of the topic and the availability of many excellent reviews covering different aspects of the physics of open quantum systems, we will focus here on one specific issue and that is embedding the theory as usually explained in the quantum optical literature within the mathematical core developed in the mathematical physics community. Finally, we make a connection with the current view point of the dynamics of open quantum systems in the light of quantum information science, given a different, complementary, perspective to the meaning of fundamental concepts such that complete positivity, dynamical semigroups, Markovianity, master equations, etc.

In order to do this, we will restrict the proof of important mathematical results to the case of finite dimensional systems; otherwise this study would be much more extensive and potentially interested people who are not expert in functional analysis or operators algebras, could not easily benefit from this work. However, since the most important application of the theory of open quantum system nowadays is arguably focused on the field of controlled quantum technologies, including quantum computation, quantum communication, quantum metrology, etc., where the most useful systems are finite (or special cases of infinite systems), the formal loss of generality is justified in this case. The necessary background for this work is therefore reduced to familiarity with the basics of quantum mechanics and quantum information theory.

Furthermore, we have tried to incorporate some novel concepts and techniques developed in the last few years to address old problems such that those exemplified by the use of dynamical maps, Markovian and non-Markovian evolutions or microscopic derivations of reduced dynamics. We have organized the presentation as follows. In Chap. 1 we introduce the mathematical tools required in order to ensure a minimum degree of self-consistency in the review; a mathematical experienced reader may skip this part. In Chap. 2 we review very succinctly the concept of "closed quantum system" and discuss its time evolution. We explain in Chap. 3 the general features of dynamics of open quantum systems and its mathematical properties. Chapter 4 deals with the mathematical structure of a very special important dynamics in open quantum systems, which are the Markovian quantum processes. The microscopic derivation of Markovian quantum dynamics is explained in Chap. 5, whereas some methods for obtaining non-Markovian dynamics are briefly introduced in Chap. 6.

Several interesting topics have not been tackled in this study. Examples are influence functional techniques [21, 23, 33, 37, 38], stochastic Schrödinger equations [15, 26, 39–42], or important results such as the quantum regression theorem, which deals with the dynamics of multi-time time correlation functions [15, 23, 26, 43, 44]. Moreover, recently several groups have addressed the important problem of introducing a measure to quantify the non-Markovian character of quantum evolutions [45–52]. However, despite the introductory nature of this work, we hope that it will be helpful to clarify certain concepts and derivation procedures of dynamical equations in open quantum systems, providing a useful basis to study further results as well as helping to unify the concepts and methods employed by different communities.

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