Preface

Quantum mechanics has shown unprecedented success as a physical theory, providing astonishing accurate predictions, but at the same time it has forced upon us a new perspective on the description of physical reality.

While Schrödinger's equation applies to the dynamics of an isolated closed system, the treatment of an open system setting appeared as an essential ingredient in the very formulation and understanding of the theory since its very beginning. Indeed, the very formulation of a measurement process, allowing to extract information on the state of the system of interest, depends on the analysis of its interaction with an external system, typically with very different features, such as being macroscopic or in a specially prepared initial state. The search for a more realistic treatment of the measurement process as the result of the interaction between two systems, ultimately to be both described by quantum mechanics, has lead to important improvements in the formulation of quantum theory. A basic motivation for the consideration of open quantum systems rests on the conceptually unfeasible, and experimentally often too inaccurate, idealization of a perfect shielding of the system of interest from the external environment. The development of the formalism of open quantum systems has also led to a deeper understanding of the very structure and features of quantum mechanics. In particular it sets the framework in which any experiment testing the foundations of quantum mechanics or willing to discriminate between quantum mechanics and alternative theories has to be considered. More recently also the notion of non-Markovian quantum stochastic process has been the object of intense investigations. This seminar aims at reporting about recent results in the foundations of open quantum systems and its connection with the most advanced experiments testing the basic features of quantum mechanics, from the microscopic to the macroscopic regime.

In recent years important progress has been achieved both in the theory of open quantum systems as well as in the experimental realization and control of such systems. A great deal of the new results is concerned with the characterization and quantification of quantum memory effects and with the extension of the standard methods to the treatment of non-Markovian quantum processes. To this end, novel mathematical methods and physical concepts have been developed. Examples include the idea to quantify the exchange of information between the open system and its environment in terms of the distinguishability of quantum states and to interpret the backflow of information from the environment to the open system as characteristic feature of quantum non-Markovianity. Another example is the idea to characterize memory effects of quantum processes in open systems through the concept of the divisibility of the corresponding quantum dynamical map. Both ideas also lead to a quantification of the degree of memory effects in open quantum systems. Experimental realization of non-Markovian quantum systems and measurements of the degree of memory effects have been carried out in both photonic and trapped ion systems. A further important research topic is the study of the impact of classical or quantum system-environment correlations. Several general schemes have been developed theoretically and implemented experimentally which enable the detection of such correlations by means of only local operations acting on the open system. Examples of applications are the experimental determination of initial correlations in photonic systems, and the local detection of quantum phase transitions in trapped ion systems. In addition to these advances in the general characterisation and classification as well as in the experimental detection and control of quantum processes in open systems, there has been important conceptual and technical progress in the analytical and numerical treatment of strongly coupled non-Markovian systems. Relevant developments have also been put forward in the microscopic modelling of such systems employing, for example, collision models to derive large classes of physically admissible quantum master equations.

This volume collects some recent developments in the field of open quantum systems and foundations of quantum mechanics that were the subject of the 684. WE-Heraeus-Seminar on "Advances in open systems and fundamental tests of quantum mechanics". The event was generously funded by the Wilhelm und Else Heraeus-Stiftung and took place in the beautiful environment of the Physikzentrum in Bad Honnef, Germany, in December 2018.

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