Preface

'Coherent Evolution in Noisy Environments' was the title of an international school at the Max-Planck-Institute for the Physics of Complex Systems in Dresden, Germany, from 2 April to 30 May 2001. Yet, this is also the general theme which a growing community of physicists is contemplating as it comes to monitor, guide, or even control the time evolution of isolated quantum systems. The latter can never be *perfectly* isolated (be it for the purpose of observation) from their environment – which is noisy (since never under complete control) – and will therefore exhibit traces of this, possibly residual, coupling on sufficiently long time scales. However, it is precisely the *coherent* nature of its time evolution which makes an isolated system *quantum*, and it is the detrimental influence of dissipation and of noise fed into the system from the environment, which induces *decoherence* as time evolves.

Given the last two decades' extraordinary progress in the experimental art of isolating single quantum objects (which Schrödinger could only think about in a, by now, famous thought experiment), the theoretical understanding of (de-)coherence and its implications has re-emerged as an important issue of fundamental relevance. Feynman's remarks on the simulation of complex quantum evolution using quantum systems appears to become a more realistic enterprise; moreover quantum cryptography, communication, and computation are identified as emerging key technologies of our young century. If these fields shall guarantee some share holder value on the long run, our theoretical understanding of the coherent evolution of quantum systems in the presence of noise, and, hence, of decoherence, needs a considerable sharpening.

Many and rather distinct subdisciplines of physics and mathematics have their word to say in this context. Whilst quantum opticians arguably come up with the cleanest experimental conditions – which allow for a highly reductionist approach to the quantum world – the condensed matter and mesoscopics communities have to fight with an abundance of imperfections which invites strong input from statistical physics. With some reason one might say that the former can tell us a little more about coherence (and controlled decoherence), whereas the latter are closer to a general theory of decoherence with less stringent simplifications. Nonetheless, both communities are expected to intensify their communication – given the recent realization of simple models of solid state transport theory in quantum optical experiments. Finally, the novel point of view of *quantum information theory* provides a general framework for coherence, decoherence, and quantum information processing in quantum cryptography, communication, and computation, and receives input from mathematical physics as well as from pure mathematics.

It was the purpose of the school at the MPI-PKS in Dresden to make these different communities listen (and speak) to each other, to convey their different languages, distinct methodologies, and different key challenges to the young and eager in these different fields. If we were able to reach this aim, at least partially, this was the merit of the lecturers of this school. Each of them enthusiastically took on the burden of preparing and delivering between 6 and 10 hours of lectures, sometimes gave additional sessions, and actively participated in the students' seminars and informal discussions, as well as in the other lecturers' courses. Therefore, we should like to thank Hans Briegel, Berge Englert, Gert Ingold, Burkhard Kümmerer, Panagagiotis Lambropoulos, Mark Raizen, Walter Strunz, Steven van Enk, Harald Weinfurter, and Kurt Wiesenfeld, for their crucial contributions to this school.

Towards the end of the event, some of us agreed that the lectures should be conserved, and this idea was strongly encouraged by the two co-organizers of the school, Reinhard Werner and Anton Zeilinger, whom we are very much indebted to for their constructive support in all respects. The result is this present book, which contains a good part of the school lectures, and an additional contribution by Keyl and Werner. It starts out with Ingold's outline of a rather general quantum treatment of dissipation – reflecting the point of view widely spread in the condensed matter and mesoscopics community. Then, Englert and Morigi give a detailed outline of the algebraic treatment of dissipation in the (possibly periodically driven) damped harmonic oscillator, an open quantum system of paradigmatic importance in quantum optics. With the micro-maser as its experimental realization in mind, these lectures constitute – in some respect – the seed for the subsequent chapters by Wiesenfeld et al. and Kümmerer. Both of them deal with stochastic processes, though in rather orthogonal languages, and within rather different contexts. Wiesenfeld et al. discuss the potentially *constructive* role of noise in classical and quantum systems in the presence of some nonlinearity, whilst Kümmerer spells out the mathematical framework of quantum Markov processes. Kümmerer's lecture also provides the general mathematical background of a good part of quantum information theory, and of the corresponding treatment of decoherence as the small system's entanglement with the environment. This latter point of view is elaborated on in Strunz's lecture, which – through the discussion of an experimental realization in the Paris micro-maser setting – is somewhat entangled with the contribution of Englert and Morigi, and rephrases aspects of quantum stochastic calculus already touched upon by Kümmerer. Strunz' treatment of decoherence in phase space is complemented by Aschauer and Briegel, who directly address decoherence in the context of quantum communication, and notably its detrimental influence on quantum entanglement. In particular, they develop efficient strategies to counteract decoherence through the *controlled disentanglement* of the (quantum) carrier from the environment. Finally, again in a more mathematical language, Keyl and Werner show how quantum data can be protected against decoherence when sent through noisy quantum channels. They also come up with quantitative bounds on the tolerable error rate for such strategies to work.

We believe that this collection of contributions from quite distinct areas nicely illustrates how those areas are slowly getting closer – propelled by some progresses made in physics and mathematics during the last couple of decades – and that we witness how a common language emerges in this exciting area of fundamental research.

Let us finally express our gratitude to all those who made possible the school, and as a direct product thereof this book, through their support and concrete efforts behind the scene: Claudia Poenisch, Christian Caron, Helmut Deggelmann, Torsten Goerke, Heidi Naether, Christa and Klaus Quedenbaum, Andreas Schneider, Hubert Scherrer, Andreas Wagner, Jan-Michael Rost, and the Max-Planck Society.

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